TECHNICAL MANUAL

FOR LOW PRESSURE

CHAMBER OPERATORS

DIVISION OF AVIATION MEDICINE

BUREAU OF MEDICINE AND SURGERY

AVIATION HYGIENE

A guide for the instruction of hospital corpsmen in low pressure chamber technology

AVIATION HYGIENE TRAINING UNIT
U. S. NAVAL AIR STATION, SAN DIEGO

This manual has been prepared for the instruction of Low Pressure Chamber Technicians. The Bureau of Medicine & Surgery desires to acknowledge the contributions made by the following officers to the preparation of this manual:

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ERRATA

Page 6, diagram, pressure at 20,000 feet, change from 379 to 349.

Page 30, paragraph 2, line 2, change "the anoxia" to "acute anoxia."

Page 35, paragraph 1, line 1, change "undectable" to "undetectable".

Page 44, paragraph 3, line 5, change "32.3 feet per second" to "32.3 feet per second per second".

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FOREWORD

The instruction of several classes o~~f~~f hospital corpsmen as Low Pressure Chamber Technicians has resulted in the preparation of this manual. Its sole purpose is for instruction of future classes, and as a reference following their qualification.

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FORM - FUNCTION & ENVIRONMENT

The subject of the following discussions is the physiology of aviation. The problems of the physiology of aviation are essentially the same as those of any other physiology, namely the problems of the working of living matter. The special aspects of aviation physiology are introduced by the fact that flying is carried on in an environment different than that of ordinary living, and by the existence of a relationship between body function and environment. Living matter is greatly influenced by its environment - that is, it responds and reacts to all and anything about it - inside and out: heat, cold, exercise, air, water, food, feelings - everything.

Let us examine this relationship between function and environment. It will help in the understanding of the problems of aviation. To begin with, let us look at life or living. The task of defining life or living is a rash enterprise and actually of little value. For the understanding of man it is more important to appreciate certain essential characteristics of what we call life(or living processes). Needless to say, there are many complexities, and simplifications must be made. Biologists (students of living matter and processes) begin with a discussion of the unit of living matter, the <u>cell</u>, and its substance, <u>protoplasm</u>. When protoplasm is first mentioned, a long array of its characteristics follows and includes irritability, contractility, capacity to reproduce, conduct impulses, assimilate food-

stuffs, secrete, etc. Protoplasm is justly called the physico-chemical basis of living. The structural unit of living matter is the cell, which consists basically of a membrane wall (the cell wall), protoplasm, and a control unit within the cell (the nucleus). Wherever cells specialize in a particular characteristic or function of protoplasm, and are grouped together, the mass is called tissue. For example, cells specializing in conduction of impulses constitute nerve tissue; cells specializing in contraction constitute muscle tissue. It is an attribute of living matter to adjust and alter its form(or structure) to its function, and vice versa, and as a result the structures of various tissues and the cells composing them are modified according to functions. Incidentally basic characteristics of protoplasm usually persist, even though specialization has occurred.

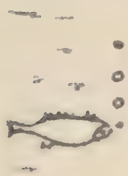
The body is composed of tissue, which in turn is made up of cells. Although each cell has its individuality, the body must be considered as a single unit - as a whole. This concept of considering the body as a single unit made up of many small units all reacting to various conditions and in turn influencing the whole body is known as the concept of the organism as a whole.

The concept can be visualized in a way by watching the response of a cat to a strange dog.

First the eyes and the nose pick up stimuli, light waves and chemicals, and report via nerves to the brain; from the brain "messages" are flashed - fear is instilled - the adrenal medulla secretes adrenalin - the muscles tense for action -the hair stands on end to afford more protection in combat - the heart beats faster -glucose and oxygen are utilized at greater rate - and so forth. Many separate parts all coordinated into action of the organism as a whole.

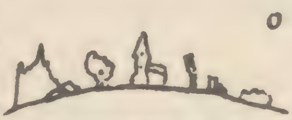
We are particularly interested in the organism's reaction to its environment. Environment, in the widest sense, means everything - everything which is outside and inside of the body. The temperature, humidity, light, sound, smell, - the feelings, experiences, thoughts, all go into the making of the

environment, and, as such, influence the bodily reactions. The bodily functions react to the various states of energy and matter of the surrounding environment, and long periods of constant or repeated exposure to particular conditions may result in bodily adaptations.



During the many thousands of years of development, plant and animal forms have evolved and adjusted to their environment. Witness the animal and plant life of the desert - cacti, llama, camel, and hosts of others do well under desert conditions. Fish are peculiarly adapted for living in the water, birds for flying, and so on and on. The long time influences and adaptations made us what we are.

Aside from the responses to evolutionary influences, the body has a remarkable capacity to adjust to immediate environmental changes. These responses are of course limited. For example, man can live on the Sahara Desert or in Greenland, at the equator or in the polar regions, but he cannot live in temperature above 160 degrees F. nor below -100 degrees F. Man can rest quietly or perform work in an amount equivalent to about one-fourth horsepower. He can adjust to various conditions of the environment within a limited range.



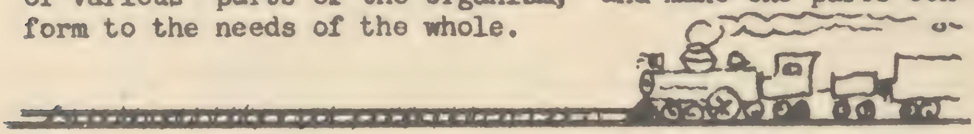
The natural environment of man is the earth's surface, and even there within limitations. Within the range of conditions upon the surface of the earth man adjusts moderately well. The realm of flying, of aviation, presents, however, a new and different environment, one which extends beyond the limits of man's natural adjustability. The fact that aviation presents new conditions - new conditions in regard to environment, positional relations, light, sound, vibrations, etc., and that the functioning of the organism(physiology) reacts to changes in the state of the environment, forms the basis of the physiology of aviation.

We shall examine some of the fundamentals of physiology, and then study the environment of aviation: the atmosphere.

FUNDAMENTALS OF PHYSIOLOGY

Physiology is concerned with the problems related to how the living organism works in its normal surroundings and how it reacts to its abnormal surroundings. A man walks. We see how he manages to regulate the orderly movements of arms, legs, and body without thinking about it. To understand even such an apparently simple procedure, we explore the workings of various parts. We study the muscle movements, the circulation of blood, the nerve control, and various other processes.

In the study and understanding of bodily behavior a synthetic or unifying point of view must be accepted. This point of view is expressed in the concept of the organism as a whole. This concept deals with the individual organism as it adapts itself to the demands of the changing environment and variable activity. The point of view reveals the existence of some unifying or integrating force which coordinates the workings of the various separate cells, tissues, and organ systems into a unity of the organism as a whole. These integrating or unifying forces act throughout life, regulate the growth and development and function of various parts of the organism, and make the parts conform to the needs of the whole.

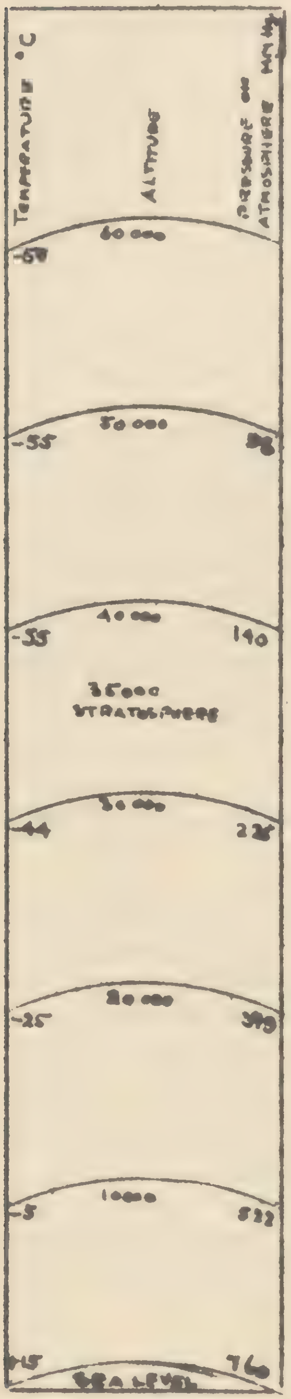


The human body is often considered an engine. This is partly correct, but from one point of view the body bears very little resemblance to man-made machines. Man-made machines, within wide limits, are stable whether the machine is acting or at rest. There is no such state of stability in the human machine. The living organism does maintain a semblance of a constant state, but on close examination we see that this constant state of the living organism is due to many integrated chemical and physical changes, constantly making fine adjustments to conditions imposed upon the body. In this task the blood plays a most important role as an instrument of keeping a uniform internal environment. The blood provides this internal environment, and is in close contact with every single cell in the body. The blood supplies the tissue with foodstuffs, with oxygen for carrying on oxidation which releases energy for maintaining activity of the cells, and the blood also removes the waste and excess products.

In order that each cell carry on its activity, and in turn that the organism carry on its activities, it is necessary to have a source of energy. The problem is essentially the same for the body as it is for any other engine. Energy is needed for activity, and the amount of energy needed is dependent upon the demands made by the degree of activity. This means simply that a man running at top speed demands more energy than one at rest, that an actively growing child needs more than a senile old man. The pattern followed by the energy requirements and utilizations of the body is the same as any engine and follows the laws of thermodynamics. The organism has as its source of energy the foodstuffs, in specially processed states, which it has ingested and stored; the release of these energies are essentially controlled by the oxidation (the combining with oxygen or burning) of these foodstuffs. The energy exchanges in the body are called the metabolic processes, and a resting man will have a certain rate of energy release which is called the basal metabolic rate. The energy exchanges under conditions of activity are greater, and so are the metabolic rates. In the proper understanding of physiological processes it is important to realize that energy is needed for every function, and fundamentally the energy is gotten by the chemical reactions of the oxygen-foodstuff combination.

The adjustments which the body - cells, tissue, and organs - makes in order to maintain stability of the organism as a whole, need energy and this constant functioning assumes the greatest share of the metabolic activity. Whenever a new demand is made, whether it arise from a change in internal environment, such as the ingestion (taking in) of foodstuffs, or a disease process, such as an infectious disease, or from an external change such as a drop in the surrounding temperature or a marked change in the altitude of the organism, or increased physical exertion - the energy demands of the body are increased, and more foodstuff is used and more oxygen is needed. In our study of the reaction of the organism to such changes in environment as are introduced in the performance of modern flying we will see how the demands upon the body are increased, the limitation to which it is extended, and the means taken by man to extend the natural limitations.

PHYSICS OF ATMOSPHERE



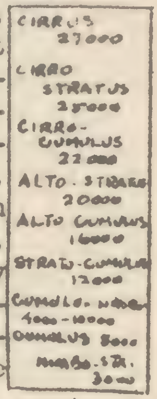
No adequate understanding of the function of the human body can be made without an understanding of its environment. This is particularly true in regard to an adequate understanding of the bodily reactions in flight. The special state of the environment in which aircraft and aircraft personnel operate is the atmosphere. It is for this reason that we shall discuss the atmosphere of the earth with respect to the physics of the air in relation to human physiology. We shall concern ourselves with atmospheric composition, pressure, temperature, density, and so on, at sea level and at various altitudes.

The earth is surrounded by an envelop of a mixture of gases and water vapor which is held close to it by the force of gravity. This layer of gases is about 100 miles high, and contains about 78% of Nitrogen, 21% of Oxygen, and the remaining one percent contains traces of Carbon Dioxide, Hydrogen, Helium, Neon, Argon, Krypton, and Xenon. We are primarily concerned with three components of the air, exclusive of water vapor. These three components are oxygen, nitrogen, and carbon dioxide. Each is important for a different reason. Oxygen is essential for living; it is as essential for the combustion of body fuels (foodstuffs) and the release of body energy as it is for the combustion of engine fuel. Nitrogen is important because it takes up almost 80% of the air, but has no particular value for living processes. Carbon dioxide has an odd role; it is an insignificantly small percentage in the air, but is a waste product of respiration and as such composes 5% of the expired

breath. A definite amount of carbon dioxide is necessary in the blood for the control of breathing and heart action but in an air sample where it is too great, life becomes intolerable.

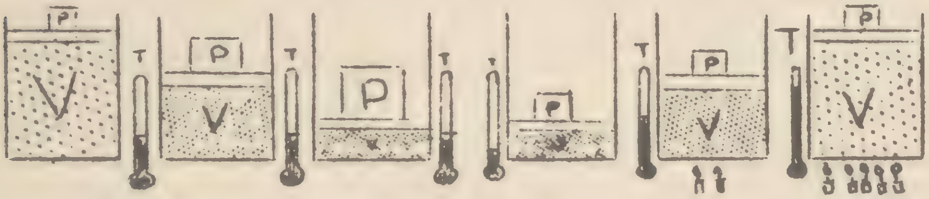
In order to test the composition of the atmosphere, samples of air have been collected by various means, including manned balloons, pilot balloons, and high altitude aircraft flights, at altitudes ranging from sea level to almost 50 miles above sea level. The percentage composition of gases is approximately the same at all these levels. Water vapor of the atmosphere varies in the cloud areas but averages about 1.2%. The percentage of water vapor gradually decreases with increasing altitude, until the air above 35 000 feet is practically dry. This is evidenced by the lack of clouds in the stratosphere.

Composition of Atmosphere



Clouds

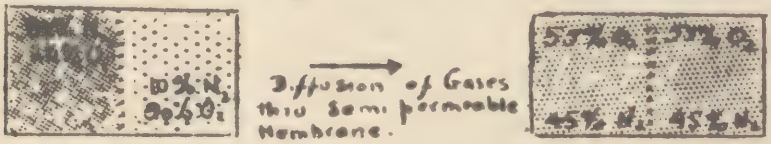
Briefly, we recall that there is a relationship between the volume, temperature, pressure, and density of a gas. To examine the atmosphere in respect to its pressure, temperature, density, and so on, it is important to review the GAS LAWS, which are the physical laws to which gases conform in their behavior. Since air is a mixture of gases, its behavior will conform to the gas laws. Take a gas



filled cylinder with a tight-fitting piston; the greater the pressure exerted on the piston, the smaller the volume - and if heat is applied the gas will expand and occupy a greater volume. Of course, when pressure is reduced, the volume is increased, and when the piston is cooled the volume is decreased.

In more technical language we state the gas laws as follows: (1) When the temperature remains constant, the volume of a gas varies inversely as the pressure; that is, the greater the pressure the smaller the volume, and conversely, the less the pressure the greater the volume. ($PV=P'V'$(1)) is the form in which this law is stated by the

physicist) (2) When the <u>pressure</u> remains constant, the <u>volume</u> of a gas varies directly as the temperature, that is, the warmer the larger the volume, or, conversely, the colder the smaller the volume. (Physicists combine these as the Gas Law: $\frac{PV}{T} = \frac{P'V'}{T'}$) (3) Since the atmosphere is



a mixture of gases ($O_2N_2CO_2NeKr$, etc.), another gas law, Dalton's Law, is relevant. It is the law of <u>Partial Pressures</u>, and states: The pressure of a mixture of gases in a given space is equal to the sum of the pressures which each gas of a mixture would exert by itself if confined in that same space. In other words, each gas in a mixture of gases exerts a pressure proportional to the percentage of the whole which it occupies. (4) Another characteristic of gases which is important, especially in understanding the physics of the air in regard to physiology, is density. Density of a gas is the weight of a standard unit of volume of gas, and can be visualized as the number of particles

(molecules) per unit volume. The greater the density the greater the number of molecules per unit of volume. The density of air (dry) is 1.293 kgm. per cu. meter. (A kilogram is equal to 2.2 pounds; a meter is roughly a yard.)

This measurement must be made under standard conditions, 15° C. and 760 mms. of mercury pressure.

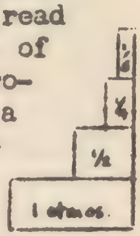
Bearing in mind the gas laws, and the fact that air is a mixture of gases, we will examine the atmosphere. Since air has density (weight) then it exerts a pressure. In order to measure this pressure we employ an instrument called a Barometer (Baros - pressure, Metros - measure).

A simple barometer is made by filling a glass tube, which is sealed at one end, with mercury, and then inverting the tube in an open dish of mercury, so that the open end of the tube is below the surface of the mercury in the dish. The column of mercury in the tube will fall to a height dependent upon the air pressure. At sea level (standard conditions) the column will be 29.92 inches, or 760 mms. high. In other words, the atmospheric pressure is great enough to support a column of mercury 760 mms. high. As a matter of fact, the weight of a column

of air one inch square from sea level to the uppermost reaches of the atmosphere is about 15(14.7) pounds. The weight of 14.7 pounds per square inch is designated as one atmosphere.

Let us return to our mercury barometer(there are other types too) and start studying atmospheric pressure. If we begin a trip starting at sea level and climb up to a mountain peak, we notice that after we have climbed up 1000 ft. the column of mercury has dropped (gradually) from 760 mms. to 732.9 mms. At 5000 ft. above sea level the column is only 632.3 mms. At 10 000 ft, the barometric pressure has dropped to 522.6 mms. We see clearly that as the altitude increases the atmospheric pressure decreases.

This relationship has a significant and striking aspect; namely, at 18 000 ft. the pressure has been reduced to 380 mms. (1/2 atmosphere); at 34 000 ft., to 190 mms. (1/4 atmosphere), and at 42 000 ft. to 128 mms. (1/6 atmosphere), so that 5/6 of the atmospheric pressure(read density) is concentrated in the lowest eight miles of the 100-mile atmosphere. With the decrease in barometric pressure as the altitude increases there is a corresponding decrease in partial pressure of oxygen. Eventually the partial pressure of oxygen gets so small that sufficient oxygen necessary for life is not available.



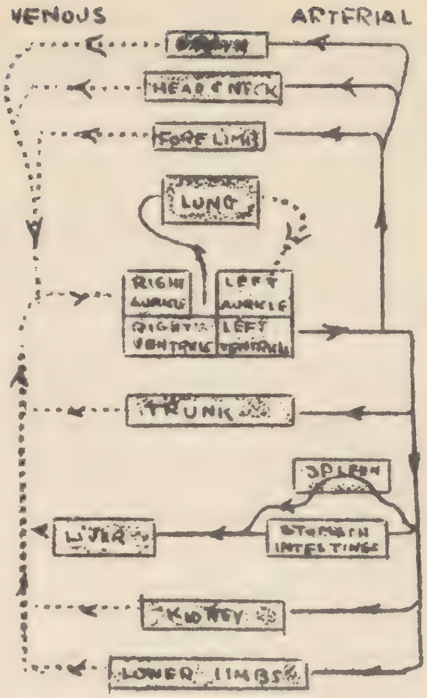
This is true because the partial pressure of each component of a mixture of gases is the product of the percentage composition times barometric pressure and while at sea level (760 mms. Hg.) the partial pressure of oxygen in atmosphere is 157 mms. (or an equivalent oxygen percentage of 20.93), at 18 000 ft. (380 mms. Hg.), the partial pressure of oxygen is 79.3 mms. (or an equivalent oxygen percentage of 10.45). Therefore, the passage through the lungs into the blood of the required amount of oxygen essential for living tissue is determined by the partial pressure of oxygen in the atmosphere, and cannot take place above certain altitudes. Therefore, in order to maintain sufficient oxygen pressure, the percentage of oxygen in the inspired air must be increased ($P\ O_2 = \%\ O_2 \cdot P\ Air$), until finally 100% oxygen must be used at high altitudes.

The table shows the relationship between altitude, barometric pressure, oxygen pressure, and oxygen percentage equivalent.

Altitude (Feet)	Barometric Pressure (mm.Hg.)	Oxygen Pressure (mm.Hg.)	O_2 Percent Equivalent
0	760	159.0	20.96
3,281	670	140.4	18.40
6,562	593	124.5	16.40
9,842	524	109.8	14.50
10,300	506	105.9	13.00
16,404	410	85.9	11.30
18,000	380	79.5	10.00
22,966	320	67.0	8.80
28,000	253	53.0	6.90
34,000	187	39.0	5.16
40,000	149	32.0	4.20
42,000	128	26.7	3.52
50,000	90	18.8	2.40

TEMPERATURE: The study of the structure of the atmosphere reveals an interesting relationship between the altitude and the air temperature. Roughly, there is a decrease in temperature of 2 C° for every 1000-foot rise in altitude. This approximate relationship is true until 35 to 36000 ft. is reached, whereafter the temperature remains rather constant, varying between -55 to -65° C. This "constant" temperature zone is called the stratosphere, and this region of the atmosphere is free from water vapor (and consequently icing problems) and free from storm effects. The extreme cold of high altitude has a direct bearing on physiologic function and will be discussed later.

THE HEART IN AVIATION



SCHEMA of CIRCULATION

Having discussed the relationship of function to environment and some fundamentals of bodily function, and having examined the atmosphere which is the body's environment, we shall proceed to a discussion of some of the bodily systems with special regard to their action in conditions of aviation.

The cardio-vascular system, that is the heart, blood vessels, and the blood, has the important function of maintaining and controlling the internal equilibrium of the body. This means that it is the task of this system to (1) carry all essential material - foodstuffs, oxygen, minerals, vitamins, enzymes, and hormones - to the tissues, (2) to remove waste products from the tissues, and (3) to maintain the internal stability of the organ. The heart is the pumping device of this system, and its main function is to create adequate mechanical forces for the circulation of the blood throughout the body. To this end the heart is constructed of special types of musculature known as cardiac muscle, and from the very early stages of embryonic formation to the death of an individual this muscle continues periodic contractions.

In briefest outline we can say of its anatomy that the human heart consists of four chambers, namely, two auricles and two ventricles. The auricles are relatively light in musculature. They are the entrance chambers into which the blood arrives from the general circulation. Blood from the body returns via the right auricle and from the right auricle passes down into the right ventricle, which is a very muscular chamber and which pumps the blood through the pulmonary artery into the lungs. The blood which has been oxygenated, that is, mixed with oxygen, returns to the heart, via the pulmonary vein, into the left auricle, and passes from the left auricle into the left ventricle, which is the master pump chamber so to speak, and which pumps the oxygenated blood through the aorta and its subsequent branches and divisions throughout the body until smaller and smaller

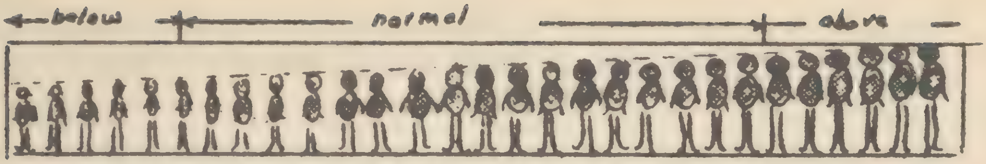
subdivisions of blood vessels, from large arteries to small arteries, to arterioles, through the capillaries, and then from the capillaries into the venules and veins back to the heart. The capillaries have intimate contact with the body tissue.

In this discussion we are concerned chiefly with the control of the heart rate and the blood vascular system, with especial regard for the changes which occur in flying. First let us understand that the blood vascular system, in carrying on its main task of maintaining internal equilibrium, is a very dynamic and constantly changing system. A sudden shocking noise will increase the heart rate. A flattering remark or an embarrassing situation will result in a change in the caliber of the peripheral blood vessels, particularly around the face. A half-dozen quickened steps

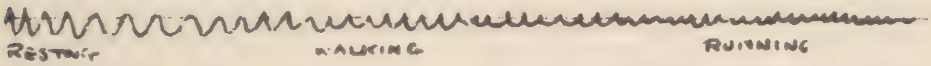
will quicken the heart rate. These are gross and obvious changes. There is an infinite and continuous series of changes to the internal and external environment to which the cardiovascular system is perpetually reacting. We shall concern ourselves with many of the various changes in the cardiovascular system which are associated with conditions of flying, but in this particular discussion we will focus our attention upon the heart. We will concern ourselves with the normal heart rate and its control, with minute volume, the relation of the heart to oxygen consumption, and the reaction of the heart to changes in altitude.

From your experience in aviation medical examination you recall that great importance is placed upon the examinee's heart system. The circulatory efficiency rating (the Schneider Test), which has a very important place in the medical examiner's routine, is an index primarily of cardiovascular efficiency. The importance which is attached to the cardiovascular system and pulse rate, resting and after exercise, is a real and significant one. Let us look to the reasons.

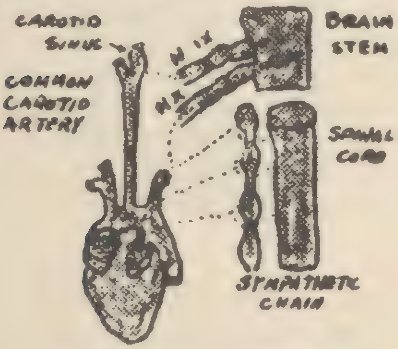
The normal or average pulse rate of an adult, healthy male ranges from 60 to 90. A word here about the meaning of "normal" and "average". You will be asked often by some enlisted man or officer, after you have taken his pulse and recorded, for example 84, "Is 84 normal pulse?", or the figure may be 72, or 68. There is a general impression that the normal pulse is a particular and finite number and this impression is an erroneous one, based upon the lack of understanding of the heart function. The average-sized person on measuring his height rarely asks whether 66½" is THE



normal height nor on weighing 168 lbs. does this person ask whether 168 is THE normal weight. Insofar as our body size is concerned we have accepted the fact that normal or average means normal or average within a range. A 23-yr. old man may be 5'4" or 5'3", he may be 6' or 6'1", and there is no question about his height being a normal height. This same type of thinking must be associated with the pulse rate; as a matter of fact, very much more so, for, although the normal pulse rate ranges from say 60 to 90, it is perfectly normal for a particular individual's pulse to range



from 55 to 90 and higher. A man at rest or immediately after waking in the morning, who has a pulse rate of 55, has a normal pulse. On jumping out of bed and doing a few brisk setting-up exercises, it will be normal for his pulse to climb to 95, perhaps even 110. This concept of the normality of variation, or the range of normal, is a very fundamental one in all biological problems, and understanding it gives the student of physiology a real working tool.



EXTRINSIC CONTROL

INTRINSIC CONTROL

This variation in pulse rate is regulated by two factors. The extrinsic nerve supply is composed of the vagus nerve, which tends to depress the heart rate, and the three cardiac nerves descending from the sympathetic chain in the neck. Stimulation of the cardiac nerves causes the heart rate to increase. The intrinsic nerve supply is composed of the sino-auricular node where the impulse, or exciting factor, arises. These impulses travel over the auricular muscle until they come to another structure, known as the A-V node (atrio-ventricular). This structure allows only a set number of impulses to go through it and down the bundle

of His (a communication system within the heart muscle), where the musculature of both ventricles are activated and ventricular contraction occurs.

Each of these systems is independent of the other, but each one modifies the action of the other. If the extrinsic nerve supply is completely removed the heart will continue to beat with its independent rhythm. It is a result of impulses going to the brain from the carotid sinuses and from other sensory nerves from the skin, eyes, ears, etc., and then to the heart from the brain through the extrinsic vagus and sympathetic cardiac nerves which activate the different pulse rates under various conditions.

The blood supply for the heart, that is, the blood which nourishes the heart proper, is supplied via the two coronary arteries. These arteries arise in the aortic bulb and during cardiac diastole (relaxation) the openings are free and blood enters the arteries. During systole the cardiac muscle is contracted and the blood is forced into the cardiac sinus which opens into the right auricle.

Now a word about pulse rates and blood pressure. An increase in pulse rate does not necessarily mean an increase in blood pressure. A rapid pulse may not be pushing as much blood out into the circulation as a slower rate with a more efficient stroke. The minute volume is the important factor. The cardiac pump needs a sufficient volume of blood returning from the general circulation to allow it to contract properly. In shock-like states there is often found the very rapid, thready pulse, with a very low blood pressure. These rapid, ineffectual strokes of 120 a minute will not push out nearly as much blood as a slow efficient rate of 70 a minute.

This condition is probably due to the fact that the heart is not receiving enough blood back from the peripheral circulation and consequently does not have a sufficient volume of blood to adequately fill the ventricles. There are other conditions in which the pulse rate is slow, but the blood pressure is still low and the person may be in shock. This is due to the fact that the stroke, or contraction of the cardiac muscles is too weak to push a sufficient volume of blood into the aorta. This is the type of cardiac response usually seen in anoxic shock.

While flying it is common to encounter conditions in which the heart must use more energy to pump faster; the heart itself requires more oxygen and food. The nervous system must be able to transmit the initiating impulses when

these conditions are met. The tone of the heart muscle must be normal to insure an adequate pressure within the vascular system.

It is apparent now why flying personnel must have good hearts. The changes which must be met by this organ in high altitude flying require a strong heart muscle to withstand the anoxia, and the general physical condition must be good to insure an adequate venous return to the right heart. A diseased heart muscle cannot be expected to respond adequately to conditions of anoxia under which perfectly normal people fail. The nervous mechanism of the heart must be normal to enable the cardiac muscle to receive the correct number of impulses in the right rhythm so that compensation may take place. The coronary arteries must be normal so that the aviator's heart receives an adequate supply of oxygen.

RELAXATION

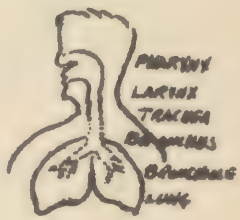
CONTRACTION

RESPIRATION PART ONE

We have seen that the cardiovascular system has the important job of carrying supplies through the body. One substance essential for living is oxygen, and oxygen is carried throughout the body by the blood stream. As important as is the heart in circulating oxygen is the apparatus for introducing oxygen into the blood. That apparatus is the respiratory system.

In order to fully understand the reasons for the need of accessory oxygen in flying at altitudes above the critical level a knowledge of the physics of the atmosphere that surrounds us, as well as a knowledge of the physiology of respiration, is required. With this knowledge we can successfully tie together the chain of events in logical sequence and arrive at an understanding.

As you follow your daily tasks you are breathing continuously, without any conscious effort. As seen by an observer it consists of the inhalation and exhalation of air through your nose and the respiratory passages, a process which occurs from twelve to sixteen times per minute. This, however, is only the first phase of respiration, known as external respiration. The second phase, known as internal respiration, consists of the gaseous interchange of oxygen, carbon dioxide, and water vapor between the lungs, blood stream, and tissue cells.

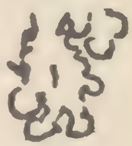


AIR PASSES THRU NOSE, PHARYNX, LARYNX, TRACHEA, BRONCHUS, BRONCHIOLES TO THE ALVEOLUS. THEN ACROSS THE MEMBRANE WALL INTO THE BLOOD.

The nose, pharynx, larynx, trachea, the large bronchi, and bronchioles serve as a piping system from the outside to the lungs, through which the atmosphere is brought to the lung tissue. The main function of the nose with its projecting turbinates is to furnish a large surface over which incoming air can be warmed to avoid irritation from cold and to remove gross impurities. The impurities are removed by hairs and mucous membrane in the nasal vestibule.

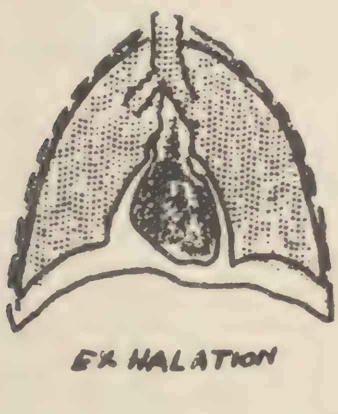
The trachea and large bronchi are partly surrounded by cartilagenous rings which make them semi-rigid. As the bronchi branch into bronchioles, this rigidity decreases until we reach the smaller bronchioles which are quite elastic. The entire respiratory tract is lined with ciliated epithelium. These hair

cells have a continuous, sweeping motion toward the nasal end of the tract, and they tend to sweep impurities into the trachea, where they may be coughed up and ejected. The terminal divisions of the respiratory system are the alveoli, or air sacs. These are microscopic air sacs which open from the bronchioles. They are approximately 1/25 inch in diameter and there are several million per lung. The total surface area of all the alveoli in the human lung has been estimated to be between 700 and 800 square feet, roughly the area of a tennis court. The walls of the alveoli are moist and extremely thin, about 1/50,000 inch in thickness. The alveoli are surrounded individually by a plexus of capillaries, so that the only actual separation between the air in the alveoli and the blood is the wall of the alveolus and the wall of the capillary. It is at this point that the exchange of gases between the body and its environment takes place. This gaseous exchange takes place across these two membranes but they are so small they offer no material resistance.

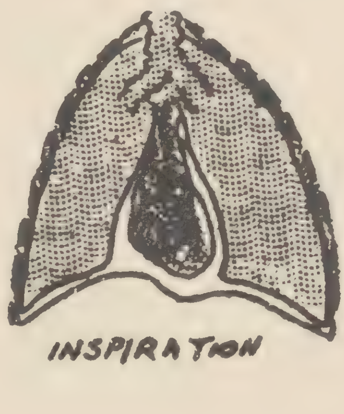


ALVEOLI OF THE LUNG

The lungs lie in the right and left thoracic cavity. They are enclosed in a membrane known as the visceral pleura, which is continuous with a similar membrane, the parietal pleura, which lines the walls of the thoracic cavity. Below the lungs lies a muscular membrane separating the thoracic cavity from the abdominal cavity, the diaphragm. The diaphragm is capable of decreasing or increasing the size of the thoracic cavity by pushing up or down. The size of the thoracic cavity may also be changed by the elevation or depression of the ribs.

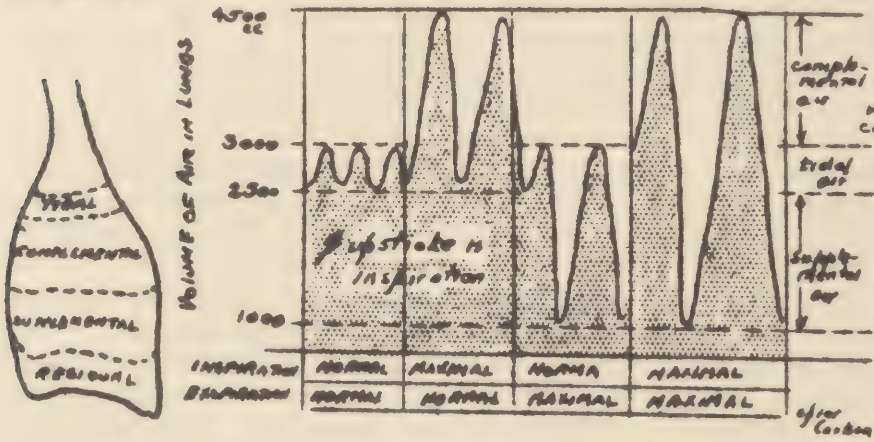


EXHALATION



INSPIRATION

Breathing occurs when the thoracic cavity is increased in size with the combined elevation of the ribs by the intercostal muscles, depression of the diaphragm, and relaxation of the abdominal musculature. When this happens, the parietal and visceral pleura are separated, creating space with a negative pressure. Since nature will not tolerate a vacuum, it attempts to obliterate this space by drawing air into the respiratory passages and expanding the lungs. Relaxation of the muscles involved results in depression of the ribs, elevation of the diaphragm. This, with the contraction of the abdominal muscles, decreases the size of the thoracic cavity and forces the inhaled air out of the lungs. The average individual inhales about 500 ccs., or one pint, of air with each inspiration. This is known as tidal air.



The tidal air, when multiplied by the number of breaths taken per minute, will give the volume of air inhaled and exhaled per minute. This is called the ventilation rate, and equals 6 to 8 liters per minute in the average man. The volume of air which can be exhaled from the lungs after the deepest possible inhalation is termed vital capacity and represents the maximum capacity to which the tidal volume may be increased.

The human body is made up of millions of tissue cells. Every tissue in the body has its individual cellular component, which, while it differs in appearance, fundamentally is doing the same thing that all other cells are doing, oxidizing the basic foods, fats, proteins, and carbohydrates, developing heat and energy and creating carbon dioxide and water vapor as waste gases. Thus in order to keep these cells living it is necessary to keep them supplied continuously with oxygen, since the body has no arrangement for the storage of oxygen, and to relieve them of the waste gases formed. This is internal respiration.

RESPIRATION: PART TWO

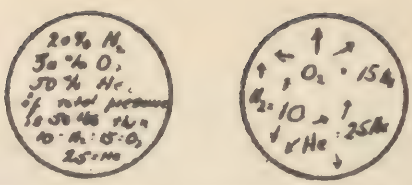
Internal and external respiration have to do with the exchange of gases from the outside of the body, through the lung, into the blood (external), and from the blood into the tissues (internal). Since the gases, in the course of this exchange, conform to the physical laws for the behavior of gases in general, let us review certain definitions and laws which apply: diffusion, Graham's Law, solubility of gases, and Dalton's Law of partial pressures.

Diffusion is the tendency of a gas to distribute itself uniformly within a confined space. The diffusion of gases is not influenced by the existence of semi-permeable membrane. Semi-permeable membranes are membranes which permit the flow of gases but restrain other particles. The body is composed of literally millions of such membranes, in fact, each cell wall is a semi-permeable membrane. The lining of the lung, that is the alveolar wall, is a semi-permeable membrane. The diffusion of the various gase s within the lung across this membrane, accounts for the passage of oxygen, nitrogen, and carbon dioxide from the atmosphere into the blood stream, and conversely.

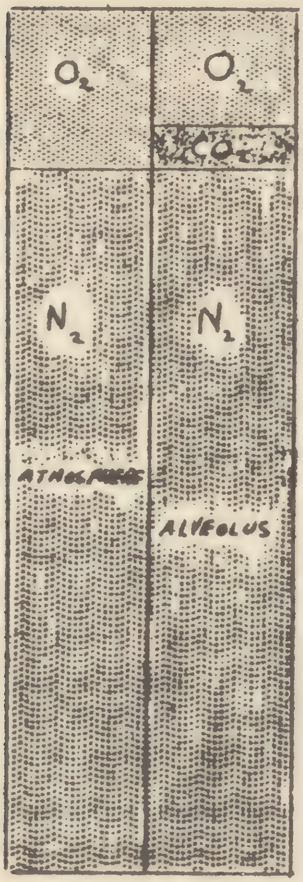
The amount of diffusion depends upon the relationship of concentrations on each side of the membrane. The natural tendency is for the diffusing gases to balance themselves on either side of the membrane and for the gases to move from the area of higher concentration to that of lesser concentration. Rates of diffusion of gases are also dependent upon the density of the gases, namely, according to Graham's Law, "The relative rate of diffusion of gases under the same conditions are inversely proportional to the square roots of the density of those gases". From this we see the importance of the phenomona of diffusion in the exchange of gases in the body. Since the diffusion is dependent upon both the pressure and the density, the partial pressure of a gas, and, therefore, the law of partial pressure which demonstrates its behavior, is also very pertinent.

In a mixture of gases the law of partial pressure obtains, that is, each gas exerts a pressure independent of the others and equal to that which it would exert if it alone were confined to that volume. For example the total pressure of air at sea level is 760 mms. of mer-

cury. The partial pressure of oxygen, a gas occupying 20% of the air, is 152. At an altitude of 18 000 ft., where the atmospheric, or total pressure is only 380 mms., the partial pressure of oxygen (20%) is 76 mms. (or 20% of 380). The partial pressure is important in our consideration of gaseous exchange in the body because the rate of diffusion of a gas, and the solution of gas (in a solvent) are proportional, among other things, to the partial pressure of that gas. This importance can be seen when the partial pressures of gas in the lung are examined.



(The discrepancy between calculated partial pressures here and those given in the table on page 9 are due to the use of 20% as oxygen percentage, for the sake of simplification, rather than 20.93% which is more accurate and used in the table.)



The gases involved in respiration are oxygen, nitrogen, water vapor, and carbon dioxide, and the partial pressures of these gases as they enter the lungs are: approximately, nitrogen 594, oxygen 149, water vapor 47 (water vapor tension of saturated air at 98.6° F.), and carbon dioxide 0.3 mms. of Hg. However, on being drawn into the lung, where this atmospheric air mixes with the alveolar air, the partial pressures are altered and the oxygen has a pressure of 100 mms., the carbon dioxide 40, the nitrogen and water vapor remaining the same.

The water vapor in the alveoli exerts a constant pressure regardless of altitude since this pressue is due to the fact that the alveolar air is saturated with water and the aqueous tension is dependent upon the temperature and the temperature remains 98.6° (body temperature). The carbon dioxide pressure also remains constant within a small range, from 36 to 40 mms.,

and is due to the continuous diffusion of carbon dioxide from the venous blood into the alveolus. The relative constancy of these two factors plays an important role in calculating alveolar partial pressures at high altitudes when breathing pure oxygen. This will be seen later.

The chart shows partial pressures of the gases of the atmosphere and the partial pressures of the alveolar gases. When these pressures are examined in percentages, one sees that the nitrogen remains roughly the same but that there is a marked difference in the percentage of oxygen and carbon dioxide existing in the atmosphere and in the alveolus. The atmosphere contains roughly 20% oxygen and 0.3% carbon dioxide, whereas the alveolus contains 15% oxygen and 5% carbon dioxide. This is the condition which exists at sea level.

APPROXIMATE PARTIAL PRESSURES AT SEA LEVEL

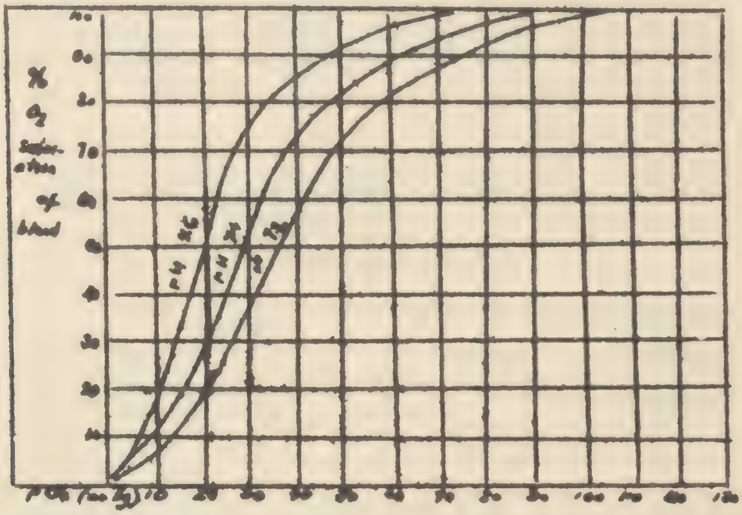
	Atmosphere	Alveolus
Nitrogen	80%	80%
Oxygen	20	15
Carbon Dioxide	0.03	5
Water	Varies	47 mms.

The solubility of a gas is the ratio of concentration of the gas in the solution to the concentration of the gas above the solution. The solubility is dependent upon a number of factors: (1) the pressure of the gas, (2) the temperature of the gas, (3) the solvent, (4) the temperature of the solvent, and(5) the solid substances contained within the solvent. In other words, the greater the pressure, the cooler the gas and the solvent and the freer the solvent is from impurity the greater the amount of gas which will go into solution.

The mechanism by which the gases enters the blood stream and by which they are transported throughout the body can be described as follows: First, the laws of physical diffusion govern the passage of the gases through the semi-permeable membranes (alveolar wall and capillary wall), and second, the transport of the gases by the blood involves mechanisms other than physical solution, namely, chemical combinations.

Were the transport of the respiratory gases accomplished by the physical solution of the gases in the fluid

component of the blood, the amount of oxygen carried in 100 ccs. of blood would be 0.2 ccs., and the amount of carbon dioxide would be 0.3 ccs. Actually, at sea level pressures 18 to 20 ccs. of oxygen are carried for each 100 ccs. of blood, and 40 to 50 ccs. of carbon dioxide. This remarkable increased ability for carrying of oxygen and carbon dioxide is due to the loose chemical combination of the oxygen with a substance which exists in the red blood cells, called hemoglobin, and in the case of carbon dioxide by the combination of carbon dioxide in the form of bicarbonate ions.



Reference to the above oxygen dissociation curve will aid in understanding the factors involved in the oxygen transport of the blood.

(1) The chemical combination of oxygen and hemoglobin is a loose and reversible one; that is, it combines with ease and it dissociates with ease.

(2) The chemical combination of oxygen and hemoglobin is related to the pressure of oxygen (partial pressure of oxygen). Incidentally, this relationship is of particular pertinence in studying altitude physiology. Notice in the curve that the percent of oxygen saturation (vertical axis) increases with the increase of oxygen pressure (horizontal axis).

(3) The affinity of hemoglobin for oxygen is high under high partial pressures and low under low partial pressures. This is evidenced in the S-shape of the curve and accounts for the ease with which hemoglobin takes on oxygen in the capillaries of the lung where the partial pressure is great, and the ease with which hemoglobin gives off oxy-

gen from the capillaries to the body tissues where the partial pressure of oxygen is low.

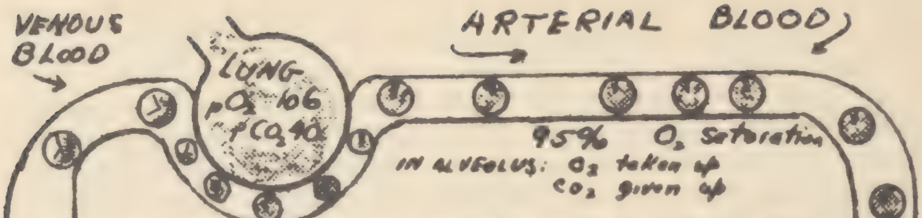
(4) The hydrogen ion concentration (pH), which means the acidity or alkalinity, affects the oxygen-carrying capacity of the hemoglobin. The blood maintains a very definite range of pH, but varies within that range. These variations are due chiefly to the carbon dioxide content of the blood, which, in turn, is related to respiration. When one breathes deeply, the partial pressure of carbon dioxide is increased and the blood becomes slightly more acid. When a substance is neutral, that is, neither acid nor alkaline, we denote the fact by stating its pH as 7.0. Maximum alkalinity is denoted by a pH of 14.0, and maximum acidity by a pH of 1.0. The blood shifts from a pH of 7.2 (slightly alkaline) to a pH of 7.6. The relationship of the pH to the oxygen-carrying capacity of hemoglobin is clearly shown in these curves. Note, for example, that at a partial pressure of oxygen of 30 mms. of Hg. that the percentage of oxygen saturation of the blood is 45 when the pH is 7.2, 57 when the pH is 7.4, and 70 when the pH is 7.6.

(5) There is a relationship between the transport of oxygen and carbon dioxide, namely, that the greater the concentration of oxygen the less carbon dioxide, and the greater the concentration of carbon dioxide the less oxygen. Since the carbon dioxide leaves the body from the alveolar capillaries of the lungs the arterial blood can carry a great deal of oxygen, and since the oxygen leaves the capillaries in the tissues the venous blood can carry a great deal of carbon dioxide.

Let us examine the gas tensions and the gaseous exchange involved in respiration from the inspiration of air to the passage of gases across the alveolar membrane thru the transport of gases to the tissues, and from the tissues, via the blood, back to the lung, to the expiration of air.

When air is inhaled at sea level it has a total pressure of 760 mms. of Hg., and an oxygen partial pressure of 152. As has been pointed out above, on being mixed in the lung, the composition of air alters, so that the partial pressure of oxygen, carbon dioxide, nitrogen, and water vapor are 106, 40, 567, and 47, respectively. This can be calculated in the following manner. The total pressure is 760 mms. Of the 760 mms., 47 mms. is water vapor.

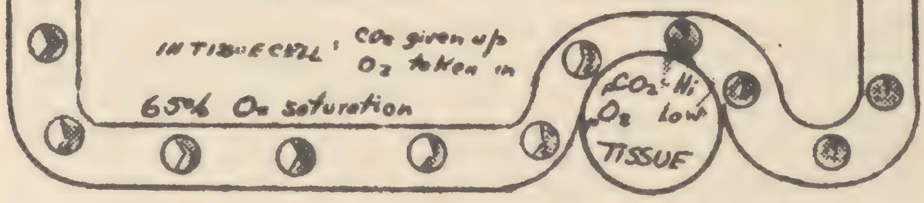
760 (T.P. - 47 (W.V.) = 713 ("Dry" Air)



The percentage composition of alveolar air, because of the dilution and because of the existence of high concentrations of carbon dioxide, now is nitrogen 80%, oxygen 15%, and carbon dioxide 5%. Therefore, to arrive at the partial pressure of oxygen within the alveolus we takd the product of the total dry air times the percentage composition of oxygen, or

$$\begin{array}{r} 713 \\ \underline{.15} \\ 106 \end{array} \text{ mms.}$$

The oxygen pressure in the alveolus of 106 mms. is greater than the oxygen pressure or tension in the venous blood. The oxygen tension in the venous blood has been measured and shown to be 40 mms. Therefore, according to the physical laws, the oxygen from the alveolus diffuses across the membrane of the alveolar wall and the capillary wall into the blood; that is, from a region of high partial pressure to one of low partial pressure. Because of the carrying capacity of hemoglobin the blood becomes saturated to 95% of its oxygen saturation, which results in an oxygen tension of 100 to 103 in the arterial blood. The arterial blood with its high tension of oxygen moves throughout the body. On coming in contact with the cellular tissues where the oxygen tension has been reduced because of the utilization of oxygen in metabolic processes (foodstuff plus oxygen to heat, energy, carbon dioxide, and water), the oxygen diffuses from its region of higher



tension (the blood) to the region of lesser tension (the tissues). At the same time the existence of a low carbon dioxide tension in the arterial blood results in the passage of carbon dioxide from the tissues into the blood. This blood returns to the heart (venous blood); therefore, has a relatively low tension of oxygen and a high tension of carbon dioxide. On reaching the lung the conditions are reversed by the passage of carbon dioxide into the alveoli and by passage of oxygen from the alveoli into the blood. (This cycle is shown in diagramatic form)

At an altitude of 18 000 ft., where the total pressure of air is reduced to 380 mms., the alveolar partial pressures are oxygen 50, carbon dioxide 40, nitrogen 243, and water vapor 47. These figures are arrived at as follows: Total pressure at 18 000 ft. is 380 mms. of Hg. The water vapor in the lung exerts a pressure of 47 mms., and therefore, must be subtracted:

380 mms. (T.P.)
<u>-47</u> mms. (W.V.)
333 mms. ("Dry" alveolar air)

The percentage of oxygen in alveolar air is 15; therefore, to arrive at the partial pressure of oxygen in the lung at 18 000 ft., take 15% of 333:

333 mms.
<u>.15</u>
50 mms.

This partial pressure of oxygen is so low that the arterial oxygen saturation is only 75% of its capacity. This low saturation results in considerable handicap to the individual because of inadequate oxygen for bodily processes. (This will be more adequately discussed under the heading of "Anoxia")

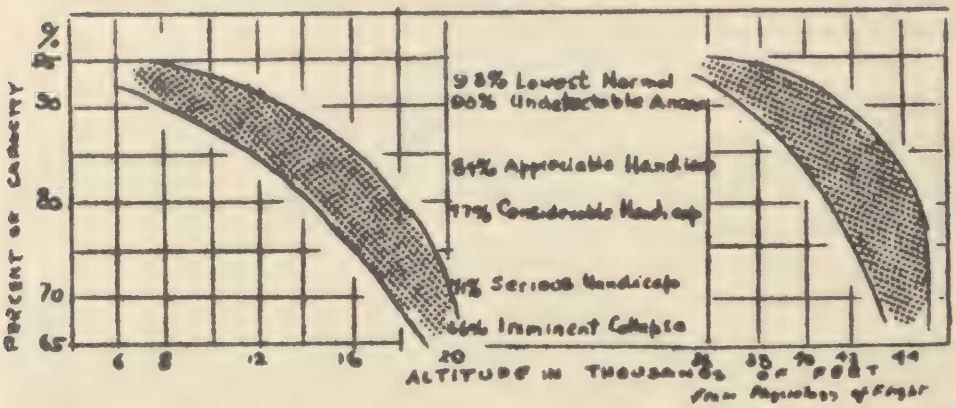
To overcome the effects of the low partial pressure of oxygen at 15 000 ft. and altitudes above, the simple expedient of breathing pure oxygen is carried out. The calculation of alveolar partial pressures while breathing 100 percent oxygen is as follows:

Total Atmospheric Pressure at 18 000 ft.	380 mm.Hg.
Total Oxygen Pressure at 18 000 ft.	380
Alveolar Carbon Dioxide	-40
Alveolar Water Vapor	-47
Oxygen Pressure breathing 100% O_2 at 18 000 ft.	293 mm.

Total Atmospheric Pressure at 34 000 ft.	190 mm.Hg.
Total Oxygen Pressure at 34 000 ft.	190
Alveolar Carbon Dioxide	-40
Alveolar Water Vapor	-47
Oxygen Pressure breathing 100% O_2 at 34 000 ft.	103 mm.

At an altitude of 30 000 ft. the alveolar gases have a partial pressure as follows: oxygen 138, carbon dioxide 40, nitrogen 0, water vapor 47. At an altitude of 34 000 ft. the oxygen partial pressure is 100, and at an altitude of 40 000 ft. it has dropped to 57. In the accompanying diagram, showing the percent saturation of arterial blood at altitudes up to 44 000 ft., one can compare conditions breathing air and breathing oxygen. The left side of the curve, which shows oxygen saturation of blood breathing air, shows that imminent collapse is reached between the altitudes of 16 000 and 21 000 ft., whereas by breathing pure oxygen, right side of curve, imminent collapse is not approached until 43 to 44 000 ft. is reached. The failure of pure oxygen to maintain life above 44 000 ft. is due to

PERCENT OF ARTERIAL OXYGEN CAPACITY



the fact that the partial pressure of oxygen at that altitude, even though it is pure oxygen without diluting nitrogen, is too low.

RELATION OF ALTITUDE TO ARTERIAL OXYGEN SATURATION & ANOXIA

Atmospheric Air			100% Oxygen
Sea Level	95%	Normal	37 000 ft.
6 000 ft.	93-95%	Lowest Normal	37 000 ft.
12 000 ft.	85-92%	Slight Handicap	40 000 ft.
15 000 ft.	77-87%	Marked Handicap	41 500 ft.
18 000 ft.	68-78%	Serious Handicap	42 500 ft.
20 000 ft.	Below 65%	Imminent Collapse	43 500 ft.

From our discussion of the anatomy of respiration it is apparent that the ventilation rate, or volume of air inhaled per minute, can be changed by either increasing the number of breaths taken per minute, or by increasing the tidal volume of each breath. The ventilation rate and the tidal volume are adjusted to meet the requirements of the body under most conditions on the ground. In order to understand the limitations of these adjustments, however,

we must have an understanding of the mechanisms by which they are controlled.

There is a voluntary and an involuntary control of respiration. By conscious effort it is possible to increase or decrease the rate of respiration for a short time. This, of course, upsets the equilibrium which is maintained by the involuntary mechanism. As soon as this voluntary control is relaxed the involuntary control mechanism takes over and automatically restores the normal equilibrium. For example, should an individual, at rest, hyperventilate, that is, breathe faster and deeper than usual, the normal carbon dioxide content of the air sacs is reduced below 5.5% and the oxygen content is raised above 14.5%. As soon as the voluntary control is relaxed, the involuntary control slows down the breathing rate until the normal equilibrium is restored.

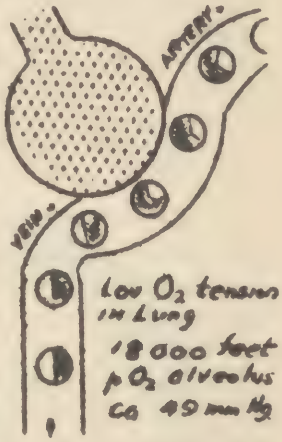
Involuntary control is exercised by the brain. At the base of the posterior brain there is a region known as the respiratory center, which controls the nerve stimuli that activate the muscles of the chest and diaphragm. The respiratory center can control the rate and depth of respiration by altering the rate and intensity of nervous impulses. Alterations in the nerve impulses are produced in two ways: (1) By changes in the character of nerve impulses arriving at the respiratory center from various control stations lying outside of the brain; (2) By changes in the chemical composition of the blood flowing through the respiratory center. This is the most influential factor of the two. The center is particularly sensitive to the carbon dioxide content of the blood. If the carbon dioxide content is increased, the respiratory center responds by increasing the ventilation rate until the carbon dioxide content returns to normal. This adjustment is quite delicate and under ordinary conditions at rest the carbon dioxide content of the blood is maintained within very narrow limits.

This effect of carbon dioxide, that is, its stimulation of the respiratory center, is utilized in life-saving equipment. Inhalators usually have tanks with mixtures of 95% oxygen and 5% carbon dioxide (or 93% oxygen and 7% carbon dioxide), so that these gas mixtures can be given to people who have become asphixiated or who have difficulty in breathing. The carbon dioxide stimulates respiration, the oxygen supplies adequate partial pressure of oxygen for bodily function.

ANOXIA

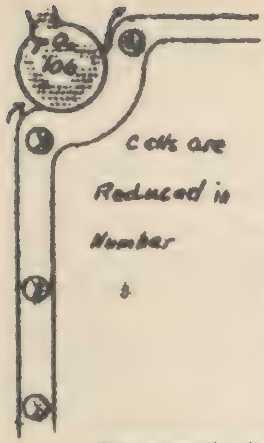
In discussing anoxia there are three terms which are frequently met, the meaning of which the student should know. Anoxia is a term used to describe oxygen lack in the body. Hypoxia is a synonymous term. Anoxemia means an oxygen lack in the blood.

Anoxia usually is classified as follows: (a) Anoxic, (b) Anemic, (c) Stagnant, and (d) Histotoxic.

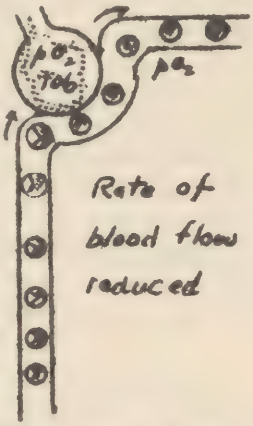


Anoxic Anoxia is that type in which there is a lack of oxygen in the arterial blood; that is, the oxygen tension is low and, consequently, the hemoglobin is not saturated with oxygen. This type can be a result of several conditions. (1) Low tension of oxygen in the inspired air, such as occurs at high altitudes, breathing inert gases, or anesthetic agents. (2) Abnormal conditions within the lungs, such as fluid in the alveoli from cardiac failure, edema from irritation caused by irritant vapors, mechanical obstruction of the air passages (diphtheria, foreign bodies, tumors), pneumonia, collapse of the lung following perforating injuries, advanced emphysema. (3) Shallow respiratory movements from any cause, apnea following voluntary forced respiration, overdistention of the gut from intestinal gases. (4) Malformations of the heart or blood vessels ("Blue Babies").

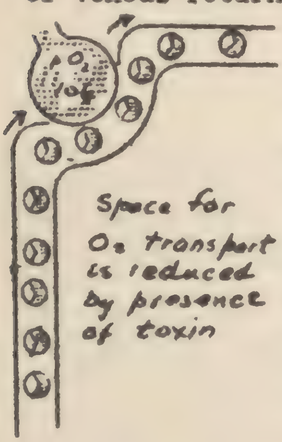
The reduction of the arterial tension of oxygen is more serious than the lack of oxygen saturation. The velocity of oxidative processes has been determined by experimental methods to be proportional to the partial pressure of oxygen. Also, the increased respirations induced by this lowered oxygen pressure wash out the carbon dioxide of the arterial blood and because of this fact the dissociation of oxyhemoglobin is much reduced. In fact, the tissues of the body are hampered in three ways in this type of anoxia: The rate of oxidation is diminished because of the lowered partial pressure of oxygen in the blood; there is less oxygen in the blood than normal; the low carbon dioxide pressure hampers the dissociation of oxyhemoglobin. This is the type of anoxia in which we are most interested in aviation hygiene, because it is this type which our flight personnel will have to combat and which we are attempting to help them overcome.



Anemic Anoxia usually is not so serious. The hemoglobin that is present is normal and there is no interference with tissue oxidation. There is not enough available hemoglobin to supply the needs of the tissues of the body under abnormal conditions. Unless it is far advanced, the patient, as long as he is quiet, experiences little or no discomfort. The principal causes of this type of anoxia are (1) hemorrhage, either acute or chronic, (2) anemia, primary or secondary, and (3) carbon monoxide poisoning.



Stagnant Anoxia is due to a slowing down of the circulatory rate. This condition is usually local, but under certain conditions may affect the entire body. The blood is normally saturated with oxygen and the tension is normal. Anoxia is developed because the slower circulatory rate allows the blood to give up a greater percentage of its oxygen and some tissues do not receive a sufficient supply because the arterial blood is starved by the time it reached the particular tissue. Any condition which improves the circulation will help relieve the anoxic state. The following conditions may produce this type of anoxia: (1) Failure of the circulation (advanced heart disease), (2) impairment of venous return, and (3) shock.



Histotoxic Anoxia is a condition in which the cells are not able to utilize the oxygen which is brought to them. The tension and the saturation may be quite normal. This type of reaction may be caused by cyanides, alcohol, or any substance which interferes with the cellular respiration. Most of these substances interfere with the action of the enzymes which enable the cell to use the oxygen brought by the blood.

In addition to the above classifications, anoxia may also be classified as follows:

(A) Fulminating Anoxia. This is rapidly induced by sudden ascents to 28 000 feet without oxygen, or breathing high concentrations of inert gases, as sometimes happens in

our dirigible crashes when personnel are caught in high concentrations of escaping helium gas. Unconsciousness may develop in 45 to 90 seconds. This type of anoxia resembles asphyxia, but asphyxia is not anoxia.

(B) Acute Anoxia. The difference between this type and the above is that the anoxia is not developed as quickly and is not as severe. This is the type of anoxia which you see every day in the low pressure chamber when the subjects are at 18 000 feet without oxygen. While every organ in the body is presumably affected in this type of anoxia, the central nervous system, the respiratory, the circulatory systems appear to be affected the most. The nature of the effect of this type of anoxia will be studied in detail later.

(C) Chronic Anoxia. This is a condition which results from long exposure to high altitudes, and even in the acclimatized individual there is a dyspnea on exertion. The symptomotology of this condition may be stated briefly as principally fatigue. Fatigue develops much faster than at sea level and recovery is much slower. This condition may also produce degenerative changes in some organs. We will examine this subject later in discussing mountain sickness.

There are several variable factors at high altitudes which may affect the physiology of aviation personnel. They have been listed as follows:

1. Lowered atmospheric pressure;
2. Lowered partial pressure of ox ygen;
3. Temperature;
4. Humidity;
5. Increased intensity of sunshine;
6. Electrical conditions;
7. Vibration.

By far the most important of these conditions is the lowered partial pressure of oxygen. It is the effect of this condition that we now study in detail and examine its effect on the different organs and systems of the body.

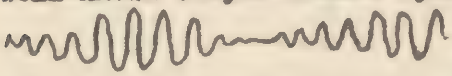
The effect of anoxia on the blood has been studied for many years and by many different investigators and from this mass of work the following conclusions may be drawn. In acute anoxia, such as we are dealing with, there is some evidence that the number of red blood cells is increased rather rapidly in most subjects, in the matter of an hour or so, and probably as a result of contraction of the spleen forcing a larger number of the cells into the blood stream.

The effect of anoxia on the heart and circulation in acute anoxia results in the following changes in the blood vascular system. The pulse rate increases, as does the contraction of the heart, until the percentage composition of oxygen in the alveolar air falls to below 9%; after this critical level the rate may remain stationary or decrease, but the minute volume output of the heart rapidly falls until that time when the anoxia affects the heart muscle and the rate falls rapidly and a circulatory collapse occurs. There is no real evidence that the blood pressure changes to a significant degree. In cardiac failure one explanation is that the intramuscular pressure is responsible for the maintenance of venous pressure and consequently the venous return to the right side of the heart. In the circulatory collapse, according to this theory, the intramuscular pressure falls first, followed by the failure of the venous return and consequent deficient filling of the heart and decrease in the amount of blood the heart is able to put into circulation. This is then followed by a fall in blood pressure, and the fast, thready pulse which we are so accustomed to seeing in shock. The pallor and sweating are a result of the contraction of the peripheral arterioles in an attempt to return the peripheral blood to the circulation.

The respiratory system is profoundly affected by lowered partial pressure of oxygen. There is a fall in the alveolar carbon dioxide pressure, which is due to the increased rate and depth of the respiratory movements. The increased rate and depth of respiratory excursions washes the carbon dioxide out of the alveolar air. This results in a fall of 4.2 mms. Hg. of carbon dioxide pressure for each fall of 100 mms. Hg. of barometric pressure. (This is disputed by some workers)

In acute anoxia there is an increase in the rate, the depth, and the minute volume of the respiration. The respiratory center is evidently one of the most sensitive areas to the lowered oxygen partial pressure. It is believed by some workers that with the decrease in oxygen the respiratory center becomes more sensitive to the carbon dioxide, which would explain the increased rate and depth of respiration. After anoxia has progressed to the point where the cells of the respiratory center have a markedly reduced excitability respiration may cease. Other effects on the respiratory system in acute anoxia are a slight depression of the respiration while the body recovers from the loss of carbon dioxide and while the bicarbonate is being reformed in the blood. Some subjects, when

in the stage of acute anoxia, show a change in the pattern of respiration, a periodic breathing which resembles the well-known Cheyne-Stokes Syndrome. The vital capacity is



decreased approximately 10% at an altitude of 15 000 ft. This is probably due to the dilatation of the alveolar blood vessels.

Another system which alters its function during anoxia is the central nervous system. Nervous tissue is the least capable of withstanding oxygen want. In anoxic anoxia the blood vessels which supply the brain dilate early, but because of the lowered oxygen pressure the brain has a deficient oxygen supply. At a simulated altitude of 28 000 ft. experimental studies have shown cortical cell changes(cells of the cortex of the cerebrum). Some of these changes may be irrevocable. Studies of the survival of nervous tissue completely deprived of oxygen, even for a matter of minutes, show the pyramidal cells of the cerebral cortex are most sensitive, the cerebellar cells next, and the medullary centers and spinal cord following, in that order.

The spinal fluid pressure is increased, as is the intracranial pressure. The mechanism for producing this pressure is not known, but may be due to the increased permeability of the capillary walls.

The entire nervous system is affected in anoxia, the finer judgments and discriminations are lost first, followed by a train of events, such as increased reaction time, loss of initiative, and slowness of neuromuscular coordination. The after-effects of anoxia are headache, fatigue, and slow recovery of finer judgment sense. The other organs of the body are also affected, but the changes just examined become so profound that death would result before secondary changes.

The type of anoxic anoxia which is most common in aviation is, of course, that which is associated with altitude. The decreasing atmospheric pressure with resultant decreasing partial pressure of oxygen in the inspired air results in a lowered oxygen tension in the arterial blood. Obviously the degree of anoxia is directly related with the degree of lowered oxygen tension, which in turn is related to the altitude. At an altitude of 10 000 ft. there is a moderate or mild degree of anoxia which has no telltale effects for the first four or five hours. There are, however, definite subclinical effects and the finer or higher brain functions are dulled. With increase in altitude there is a more marked anoxia of such a degree that from 12 to 15% of heal-

thy adult personnel will faint or become unconscious within a half-hour at 18 000 ft. (The drawing demonstrates relative degrees of anoxia at various altitudes)

As far as aviation personnel is concerned, anoxia, even though it be of low grade and not severe enough to cause unconsciousness, is a very important condition. Low grade anoxia will affect the nervous system, causing complete lack of critical judgment, a lack of motor coordination, and a false feeling of well-being.

Overcoming the effects of anoxia forms the basis of a very valuable practice in aviation medicine, namely the utilization and training in the use of accessory oxygen equipment at altitudes over 10 000 ft. The natural lowered partial pressure of oxygen is increased artificially by the use of such oxygen equipment. Thus by the use of accessory oxygen equipment aviation personnel can go from sea level to high altitudes day in and day out without any deleterious effects of anoxia.

Individuals who live at moderately high altitudes adjust themselves to their new environmental conditions. During that acclimitization to high altitudes the following events have been shown to occur: (1) An increase in total ventilation of the lungs due to stimulation of the respiratory center (reflexes); (2) Fall in carbon dioxide alveolar tension and rise in oxygen pressure; (3) Increase blood alkalinity, which is controlled to a reasonable degree by increased alkali excretion by the kidneys; (4) An increased number of red blood cells first by contraction of the spleen and later by stimulation of the redbone marrow; (5) An increase of hemoglobin in percentage and total amount; (6) An acceleration of the heart rate and an increase in cardiac output.

There is some evidence that other changes occur, but the above are more or less definite. The repeated ascent of aviators to high altitudes does not result in acclimitization. The changes occur slowly in people who live continuously for a period of several days, weeks, or months under conditions of lowered partial pressure of oxygen.

The importance of anoxia in aviation is so great that it is worth our while to reiterate salient points in the above discussion. At the same time we will correlate the Bureau of Aeronautics Technical Order 42-40 with the symptoms of anoxia at various altitudes.

The Technical Order states that in all cases of flight over 15 000 ft., regardless of duration, accessory oxygen should be used. At an altitude of 15 000 ft. the blood saturation ranges from 77 to 87%. Within this range one finds considerable handicap in performance of any physical or mental activity. Headache, slight dizziness, a slight feeling of nausea, sluggishness, and a general feeling of heaviness may be present; vision is slightly dimmed, and a feeling of confusion may exist. The individual is partially cyanotic; that is, nails, lips, and ear lobes may range from a light blue to a deep purple. As is true in all degrees of anoxia, judgment is impaired.

Above 15 000 ft., symptoms of anoxia persist and most of them are intensified; the vision is further dimmed and the cyanosis is increased. The general feeling, however, may be altered from that of weakness and sluggishness to a feeling of well-being and gayety much akin to that associated with certain stages of intoxication. Progressive increase in anoxia results of course in severe taxing of the body, with an increasingly greater degree of malfunction, weakness, stupor, coma, and death.

The Technical Order states that Navy personnel flying at an altitude of 12 000 ft. for two hours or more should use accessory oxygen. At an altitude of 12 000 ft. the arterial oxygen saturation ranges from 84 to 92%. There is appreciable handicap associated with oxygen saturation of only 84% and since the effects of anoxia are accumulative it is clear that prolonged stay at a moderate altitude of 12 000 ft. can have definite deleterious effects. The symptoms associated with anoxia at this altitude for a prolonged time are similar to those at 15 000 ft. The onset, however, is much more insidious and the decrease of critical judgment the more important effect.

The Technical Order further states that for stays at 10 000 ft. of four hours or longer oxygen should be used. The situation here is similar to that at 12 000 ft., except that since the altitude is slightly less a greater period of time for the accumulation of anoxic symptoms is necessary. An important, recently recognized condition associated with prolonged flying at 9 to 10 000 ft. is the chronic low grade anoxia. Flying personnel who experience long missions at an altitude of 8 700 ft. find themselves extremely fatigued, irritable, suffering from insomnia, loss of appetite, and a general insidious weakness. This picture does not present itself when personnel use oxygen on prolonged moderate altitude flights, since by using oxygen the accu-

mulative effects of this low grade, undectable anoxia are prevented.

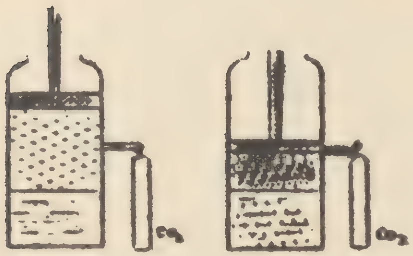
A particularly important effect of anoxia, even very low grade, is the decrease of night vision. This is discussed later.

AEROEMBOLISM

Aeroembolism is a disease produced as the result of subjecting the body to a rapid decrease of atmospheric pressure (decompression), as in the course of an aircraft flight to very high altitudes. The condition is assumed to be due to the formation of nitrogen bubbles in the body tissues and fluids.

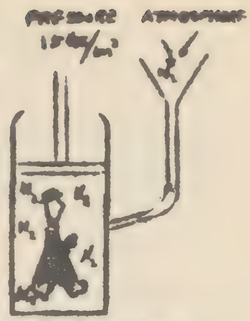
Aeroembolism is distinguished from divers' bends (Caisson's Disease) by the fact that it occurs from the decompression below one atmosphere of pressure, while divers' bends occur from decompression below two or three atmospheres.

In discussing the cause of this condition it is helpful to use an analogy. Almost everyone is acquainted with the machine that makes the common soda water in soda fountains. It consists essentially of a cylinder with piston, ordinary water, and a tank of compressed carbon dioxide. Water is put in the bottom of the cylinder and some of the carbon dioxide is allowed to flow into the space above the water. The piston is then depressed, and with the increase in pressure the carbon dioxide dissolves in the water. As long as this pressure is maintained, the carbon dioxide will stay in solution. However, if the pressure is decreased, either by lifting the piston or by letting the soda water flow into the outside air, the carbon dioxide comes out of solution. This release of pressure is what accounts for the formation of bubbles and the foaming up of carbonated drinks when the bottle cap is removed. Now, how does this apply to the human body?



The human being lives constantly in an atmosphere made up of 80% nitrogen and 20% oxygen at a total atmospheric pressure of about 15 pounds per square inch. Using our example above, we may compare the human body with the water in the bottom of the cylinder and replace the carbon dioxide with the nitrogen and oxygen of the atmosphere. The "piston" (atmosphere) is set to exert 15 pounds of pressure per square inch. Under this pressure a certain

amount of nitrogen and oxygen is dissolved in the human tissues in a manner similar to the solution of carbon dioxide in water. Since the body uses the oxygen in metabolic processes there is little of this gas existing in the free and uncombined form.



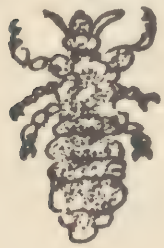
Insofar as the body is concerned, nitrogen is an inert gas and exists in the dissolved, uncombined form. As the body is taken to altitudes where the absolute pressure of the atmosphere is decreased, or, as in our analogy, the piston is raised, the nitrogen comes out of solution from the body tissues and fluids in the form of nitrogen bubbles. (Thus, at sea level pressure the tissues of the body are always saturated with atmospheric nitrogen.) It is of interest that nitrogen is more soluble in fats and oils than in water, and, likewise, in the body the fats dissolve five to six times as much nitrogen per unit of mass as does the blood itself.

The following is the sequence of events in aeroembolism. During ascent in aircraft, or in any other situation in which the atmospheric pressure is decreased, the partial pressure of the body nitrogen is greater than the partial pressure of the alveolar nitrogen. The nitrogen from the blood diffuses into the alveoli of the lungs, the nitrogen of the tissues enters the blood stream, and thence into the lung. Thus, the body tends to rid itself of its excess (expanded) nitrogen. If the ascent is slow, and the nitrogen in the body can be eliminated through the lungs as fast as it comes out of solution, no unusual symptoms occur. If, however, the pressure is decreased rapidly to at least one-half the original pressure, the nitrogen gas will come out of solution with such relative rapidity that bubbles will form in the tissues, blood, and body fluids. The most likely site for bubble formation is body tissue, which has high fat content and meagre capillary circulation. When bubbles become large enough they block off capillaries, which causes a decreased local blood supply. This blocking of blood circulation interferes with the normal functioning of the local parts, and provokes various symptoms.

The symptoms of aeroembolism are conveniently grouped according to the affected site, as follows:

1. Skin and mucous membranes
2. Bones and muscles
3. Respiratory system
4. Semicircular canals
5. Central nervous system

The skin and mucous membrane symptoms are popularly known as "The Itch". These symptoms may be classed as paraesthesia (or false sensation), and presumably are caused by collections of nitrogen bubbles beneath the skin which irritate the sensory nerve endings. These symptoms manifest themselves in various ways. There may be a sandy sensation between the eyelids and the eyes. Frequently small bubbles may be seen beneath the conjunctiva. There may be sensations of cooling or drying of the eyes. (This should not be confused with oxygen leak around the mask, or ex pirational blowing over the eyes) A generalized itching of the skin may occur, but it is more common for one area, usually near a large subcutaneous deposit of fat as around the waist or on the buttocks, to be affected. Scratching is only of temporary relief since the nitrogen bubbles are pushed from one area to another. The sensation of ants crawling over the body (called formication) is not uncommon. The sensation of excessive sweating when in reality the skin is perfectly dry, and of hot and cold flashes also fall in the general group of paraesthesia or false sensations. In some individuals, bubbles of varying sizes may be felt or seen beneath the skin and mucous membranes, particularly beneath the palmar skin of the fingers and beneath the ocular conjunctiva. This is called subcutaneous crepitation. In most cases the symptoms disappear immediately upon reaching lower altitudes (increased external pressure). A small percentage of cases retain subcutaneous induration and erythema for several days. None of these symptoms is incapacitating, but they are annoying. The occurrence of these symptoms indicates the onset of aeroembolism and should warn of the possibility of the development of more severe symptoms.



Symptoms of the joints and muscles are commonly referred to as "The Bends". Some observers believe the exact origin of the pain in the bones and muscles due to the blocking of capillaries supplying the area involved, while others believe it is due to the gas (nitrogen) pressure on or under the periosteum or the insertions of tendons about the joint. While movable joints are most commonly affected, pain is frequently felt in the region of the biceps and the posterior thigh muscles. The pain has been grouped into four arbitrary types, as follows:

Type 1. An aching in one or more areas, which is noticeable but not severe or incapacitating.

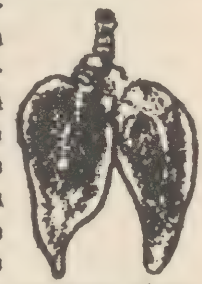
Type 2. Pain is more severe than Type 1, and of such a degree that the subject restricts his movements. Although this pain is not incapacitating it definitely lowers a man's efficiency.

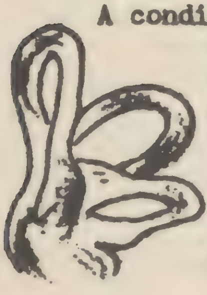
Type 3. Pain is more severe than Type 2. The person is unable to move the member affected; he becomes pale, clammy, and if not relieved will become unconscious. It is definitely incapacitating.

Type 4. Pain appears with dramatic suddeness, and is very apt to render a man unconscious in a very short time unless given immediate relief.

The bone and muscle symptoms are the most common causes of incapacity from aeroembolism. It is obvious that a pilot or crew member who is unable to move his leg or arm is a serious handicap to any mission. Descent to low altitude (greater pressure) effects immediate relief in most instances. Although there may b e some residual effects after recompression they are not common.

The involvement of the lungs in aeroembolism, popularly known as "The Chokes", is due to the collection of nitrogen bubbles in the circulation of the lungs. These bubles irritate the mucous membranes of the respiratory tract and cause burning, substernal pain and unproductive and difficult cough and a sensation of choking. The Chokes have also been described "like mixing a bromoseltzer in the lungs". The symptoms increase the individual's apprehension, and may lead to collapse. It is definitely incapacitating and relief must be provided as soon as possible to prevent serious results. Fortunately the Chokes are much less common than the two groups of symptoms described above. Immediate relief without residual effect is gotten by descent.





A condition, popularly known among deep sea divers as "The Staggers", may occur in aviators. It is presumably due to nitrogen bubbles in the fluid circulation in the semicircular canals, which stimulate false sensations of position and motion. The individual is completely confused in regard to position and movement, and behaves accordingly, much like an intoxicated person. This condition is very incapacitating and the

symptoms may persist for days, but fortunately its occurrence is rare in aviation.

Divers' "Paralysis" is probably due to the blocking of cerebral or spinal capillaries, with a resultant ischemia (blood lack) to a certain area of the brain or spinal cord. Some believe it may be due to the direct pressure of nitrogen bubbles in the spinal fluid upon the nerve roots. It will result in paralysis of that part of the body controlled by the part of the brain or cord affected. Nitrogen bubbles have frequently been demonstrated in the spinal fluid at altitude pressures equivalent to that found at 18 000 ft. Since the spinal fluid has no direct connection with the circulating blood it is probable that the nitrogen is not rapidly eliminated. This has led some investigators to believe that most of the symptoms are due to pressure (these bubbles) on the central nervous system. Fortunately divers' paralysis is extremely rare in aviation.

In the early days of high altitude bombing in this war a fairly large percentage of the bombers had to return to their bases without completing their mission, because personnel developed incapacitating symptoms of aeroembolism. There were three methods open to correct this situation. The service could employ men for high altitude flying who were resistant to the effects of low atmospheric pressures- "Bend Resistant". The physico-chemical state of the body of those who were susceptible to aeroembolism could be altered to render them less susceptible. Or, the environment of the individual could be controlled so that he would not be exposed to low pressures, even though flying at high altitudes.

To aid in the selection of bend-resistent personnel low pressure chambers were operated for the classification of individuals according to their ability to withstand the effects of low atmospheric pressures, with particular reference to the development of the symptoms of aeroembolism. The graph shows the results of tests made on one group of one thousand individuals taken to 35 000 ft and kept there for one hour. The data re-

FREQUENCY DISTRIBUTION of BENDS ACCORDING TO AGE

vealed that the younger the individual the less susceptible he is to the bends. Men in the older age groups, who have their valuable experience, need not, however, be eliminated from high altitude flying (except fighter craft), since by altering the physico-chemical state of the body a person can become resistant to bends. By breathing 100% oxygen, the partial pressure of alveolar nitrogen is greatly reduced with a resultant diffusion of nitrogen from the blood and tissues and a reduction of the nitrogen stores of the body. This is the principle of the process, "Denitrogenation", or, as it is sometimes called, "Preoxygenation". According to the best available evidence, the elimination of about 50% of the body nitrogen before ascent to high altitude renders most people protection from serious or incapacitating symptoms of aeroembolism. Fifty percent of the body nitrogen can be removed by breathing 100% oxygen with especially designed mask for one hour, provided that the individual exercises for one-half of that time. Exercise hastens the circulation rate and therefore hastens the diffusion of nitrogen from the blood.

Since denitrogenation also occurs during ascent to high altitudes and when 100% oxygen is breathed from the ground on up, the degree of nitrogen removal is greatly increased. The Bureau of Aeronautics Technical Order directs all personnel flying over 23 000 ft. to take oxygen from ground level up.

Denitrogenation, however, is practical in only certain types of combat flying, namely, scheduled missions. Bombing and observation plane personnel who are scheduled to fly at a certain time can begin breathing oxygen long enough before that time to insure sufficient denitrogenation. Fighter pilots, however, who may have to fly at any time, and who must climb at maximum rates, find denitrogenation impractical, since it would entail their breathing oxygen for long hours while at the "ready". Therefore, for fighter pilots the first and third alternatives only are applicable, that is, choice of personnel, or alteration of environment.

By maintaining the body within relatively high atmospheric pressure, even though the plane may be flying in a very high altitude, the development of aeroembolism can be prevented. That, of course, is the principle applied to the use of the pressure suit or the pressurized cabin plane. However, neither method is sufficiently developed at present to be practical for large scale combat flying.

Although it is known that nitrogen bubbles form in the tissues, and in the spinal fluid at 18 000 ft., it is rare to encounter any symptoms considered incapacitating below 30 000 ft. Practically, then, so far as aviation is concerned, aeroembolism is a disease that occurs only above 30 000 ft.

The probabilities of developing symptoms depend upon the rate of climb to the altitude and the length of time at that altitude. Thus a person might be able to tolerate 35 000 ft. for an hour, and yet become incapacitated with bends after an hour and five minutes. Also, an individual might be able to tolerate 35 000 ft. for several hours and yet develop incapacitating symptoms shortly after reaching 40 000 ft. It further depends upon the amount of muscular movement, and the degree of protection from cold. Too much movement, and chilling both abet the onset of the bends. The general physical condition, with special regard to fatigue, alcohol, and food, also enter.

ACCELERATION

The development of aircraft which are highly maneuverable at great speeds has presented the aviation personnel and the flight surgeon, who is interested in maintaining maximal health and efficiency, with definite and important problems. The reactions of the human body to great velocities, and especially to changes in rate or direction (or both) of velocity, may cause serious impairment of normal function. It is important to know the limits of these forces to which the pilot can be subjected, and how to overcome the damaging effects. To this end we are going to examine the physical and medical aspects of motion through space.

Velocity (or speed) is an expression of motion through space, and is usually indicated as $V = d/t$ (or distance per time). It is important to know that V can be uniform or varying in rate, and can be a straight, or curved, or varying direction. When a velocity is changing, the rate of increase, or decrease, is designated as acceleration (positive for increase in rate, negative for decrease).

The maximum velocity to which a man can be subjected has not been ascertained. We do know, however, that if a man is protected from wind resistance he can travel, with little effect, as fast as 600 to 700 miles per hour, as long as the speed remains constant and the direction of flight is in a straight line.

An aircraft in straight and level flight and traveling at a constant speed presents no problem to the crew. However, whenever the direction or speed is altered, accelerations are developed. The physiologic changes occurring as a result of development of high accelerations are profound and dramatic in their effect. The most common example is the "blacking-out" which occurs in pull-outs from dives or during prolonged tight turns.

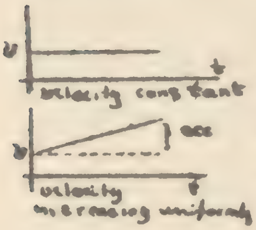
At present the high accelerations which occur in aviation and affect the pilot are mostly developed by change in direction of flight, and due to the positive or negative lift of the wings. Although catapult take-offs and carrier landings develop relatively high accelerations, their physiological significance is limited because of their short duration.

The effects of acceleration upon the body are due to the forces which act during the acceleration. These forces can be calculated from simple physical laws. First, the force developed in linear acceleration is

$$f = m \cdot a$$

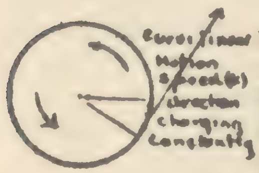
where f = fprce, m = mass, and a = acceleration.

In other words, the force is proportional to the mass of the object and to the acceleration (or rate of change of velocity).



Since most of the acceleration developed in aircraft is due to change in direction, and change in direction of path of flight is always curvilinear, the centrifugal accelerations are of particular interest to us. The forces developed in centrifugal accelerations are

$$f = mv^2/r$$

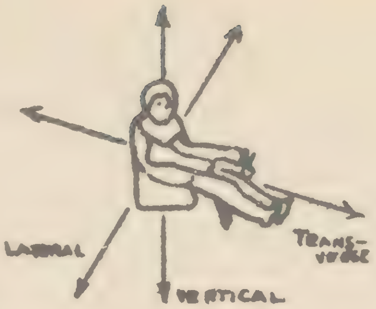


where m = mass, v^2 is velocity squared, and r the radius of turn.
From the examination of this formula it is clear that forces are increasingly greater with small radius of turn (e.g., tight turns or quick pull-outs) and very markedly increased (v^2) by increase in velocity.

In the assignment of a unit of force the pull or force of gravity has been accepted as the unit. According to the law of gravity, the earth exerts a force (or attraction)in all bodies, and if a body could fall through space without resistance, it would increase its velocity 32.3 feet per second. This is referred to as the acceleration of gravity. Under conditions of resting equilibrium the force of gravity is exerted upon a supported body. This force is equal to the weight of the body, or designated as I G.

Although the source of acceleration forces, that is, whether they arise from linear or centrifugal acceleration, is of little concern beyond the fact that most of those developed in flying are centrifugal, the axis of the body through which the forces act is of utmost importance. There are certain conventional axes which are used in aeronautics and which we will adopt. They are three in number, designated as the transverse, vertical, and lateral axes. The transverse axis passes from propeller to tail; the vertical axis passes through the pilot, from head to food; the lateral axis passes along the wings, through the fuselage.

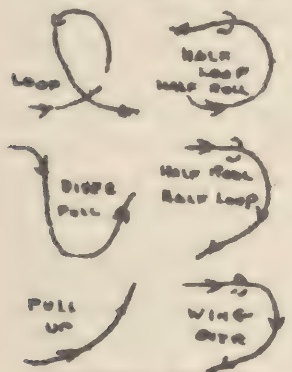
In respect to the pilot and other aircraft passengers there are two essential directions of acceleration: (1) the transverse, and (2) the vertical(or positive or gravitational) types. Transverse accelerations are encountered in linear direction with marked velocity rate changes, chiefly in catapult take-offs, carrier landings, and parachute jumps (on opening of chute and landing). The magnitude of "Gs" developed in all these cases is small, e.g., catapult starts develop 3 - 4 G, parachute opening, 5 - 6 G, jump landings 8 - 9 G, but the duration of the force is so limited that the physiological effects are slight, as long as the body is not "thrown" against some barrier.



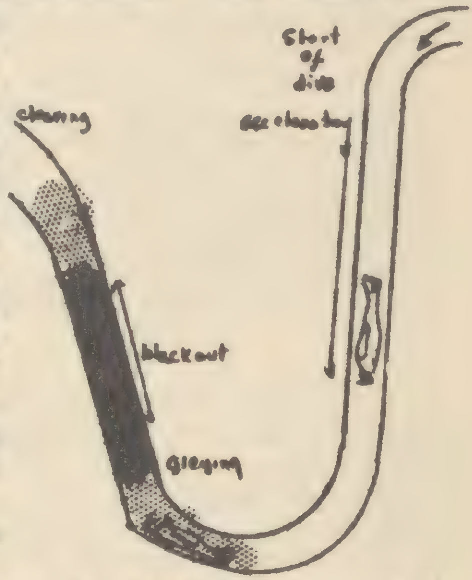
Adequate protection against transverse G forces can be gotten by proper buckling-in belts and shoulder straps, so that the effects of the forces can be minimized. Moreover, adequate buckling-in equipment greatly reduces the seriousness of most crash landings. Protection against accelerations developed in opening of parachute is limited to delaying the opening of the chute when leaving a very fast-moving craft, until speed of free fall (160 m.p.h.) is reached. The proper method of overcoming the forces of "G" in landing of parachutists is the same as "breaking" any fall, namely, spring-like bending of knee and rolling.

The problem of positive acceleration is one of greatest importance.

Changes in direction of motion account for most of the conditions in combat aviation where accelerative forces are developed to such a degree that detrimental effects occur. The simplest and most usual change in direction is that which occurs when flying in a circle or a part of a circle, or when changing from a straight line to a circle. These flight paths occur in the course of ordinary maneuvers, making turns, diving, and pulling out of a dive, etc. The movement of aircraft in a large circle around a particular focus results in a development of centrifugal forces. We can visualize the centrifugal forces by twirling a chest nut around on the end of a string. If



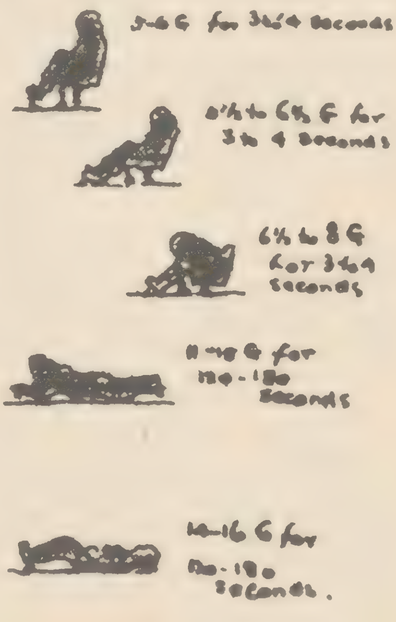
we could arrange to have a spring scales between the chestnut and the center of the circle we would discover that the weight of the chestnut increased as it was twirled around and also increased progressively as the string or radius of curvature was shortened. These conditions exist in aircraft, so that when a flyer is making a large radius turn there is usually no physiological effect. If, however, he were to make a tight or small turn at approximately the same speed, the centrifugal forces would be of so large a degree that blood would be forced from his head toward his feet and the pooled blood of the limbs would be difficult to pump back to the brain. This would result in a graying-out or a blacking-out, with a loss of vision and possibly also of consciousness. A similar condition is experienced in the sharp pulling out of a dive when a pilot, moving in a relatively straight line at a high rate of speed as he approaches his bombing target, as he pulls the nose of his plane upward general accelerative forces tend to push the bodily fluids downward (that is, maintaining the same straight line path as the first phase of the dive), with a resultant graying-out or blacking-out.



The forces encountered in dives or turns are measured in Gs. Now, as an airplane describes a circle of a radius of 1600 ft., and at a speed of 200 m.p.h., the centrifugal force will be 2G and the aviator will apparently weigh 3G, that is, his own weight plus the centrifugal force. In other words, the pilot weighing 150 lbs. would experience or apparently weigh 450 lbs. He would be pressed into his seat, his head and limbs and belly muscles would be pulled downward and his blood and tissue juices would become three times heavier. When the G forces exceed a certain limit the aviator experiences a gradual dimness of vision and blacking-out or loss of vision. If the forces are maintained or increased, the next stage is loss of consciousness. In order to overcome these effects and by adequate knowledge of the forces and conditions of blacking-out we can make certain protective arrangements. We should examine the heart and blood circulation. We know from our physiology that the left side of the heart is the pump system

that automatically adjusts its pumping forces to the work which it must do. It can lift against a pressure of 120 to 250 mms. of mercury provided that the blood flow is maintainable. When the forces of acceleration are such that they increase the weight of the blood to a degree great enough so that the flow of blood cannot be maintained into the heart, the symptoms of anoxia, blood lack, particularly of the brain, appear suddenly and dramatically. The second reason why it is difficult for the blood to maintain its flow is that in the increased weight of the blood and forces pushing it toward the extremities, there is a pooling of blood in the lower limbs and lower part of the abdomen and this blood has great difficulty in returning to the heart.

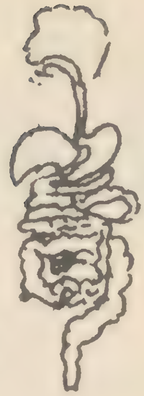
In order to overcome, to a certain degree, the effects of acceleration we carry out certain procedures which assist in the maintaining of blood flow to the heart. The first is the tensing and tightening up of the muscles of the lower extremities and of the abdomen. This can be done by conscious, or voluntary, muscular control, or, mechanically, by the use of a so-called "Anti-Black-Out Suit". The second is the reduction in the difference in level between the heart and the head. Since the heart must pump upstream, so to speak, from its level to the brain level, an upright position means a maximum difference in level, whereas a crouching position, with the head lowered somewhat, means a reduced difference in level. The logical method for effecting this positional change and preventing the pooling of blood in the lower extremities would be a cockpit arrangement such that pilots of dive bombers and fighters could handle their aircraft in a prone position. Under such conditions the centrifugal forces which act from head to foot in a sitting man would act from back to belly. Perhaps the best indication of the effectiveness of a change in position in the



overcoming of black-out can be gotten from the following comparative data. In an ordinary sitting position an average pilot can stand 3 to 4 G for a matter of 3 to 5 seconds without blacking-out. If he crouches over, he can stand from 3 ½ to 5½ G from 4 to 6 seconds. If he lies down he can stand from 11 to 12 G for a period of 120 to 180 seconds.

Another aspect of maintaining so-called G-tolerance, is the general bodily condition. A person in excellent physical condition, in excellent health, can withstand a greater amount of G-force, over a greater period of time, than can a person who is suffering from any lapse in his physical condition.

THE INTESTINAL TRACT



The stomach and intestinal tract normally contain a variable amount of gas which is always maintained at a pressure approximately equivalent to that of the atmosphere surrounding the body. Intestinal gases, like all other gases, behave according to the gas laws. Therefore, as the individual ascends in the atmosphere the volume of his intestinal gas will increase.

Altitude	Relative volume of gas
0 ft.	1 volume
18 000 ft.	2 volumes
28 000 ft.	3 volumes
33 000 ft.	4 volumes
38 000 ft.	5 volumes
42 000 ft.	6 volumes

The effect of the expansion of gastro-intestinal gases will vary somewhat with the original quantity of gases and with the rate of ascent. Thus, in the normal individual, at a slow rate of ascent of 200 to 500 ft. per minute, a feeling of moderate abdominal distention will be felt at 12 000 to 16 000 ft., with sensations of movement of gas through the intestinal tract. At that altitude, belching and passage of flatus begins and tends to continue as the altitude increases. Slow ascent rarely causes incapacitating abdominal discomfort, inasmuch as the expanded gases can be passed through the tract and eliminated. With rapid ascents of 2 000 ft. per minute, or more, the gas expands rapidly and tends to remain localized in the intestinal loops. This increases abdominal distention, and abdominal cramps of varying severity may be experienced. The abdominal distention may also be great enough to cause upward pressure on the diaphragm and embarrass respiration; it may be of such severity as to distract the man from his task or incapacitate him.

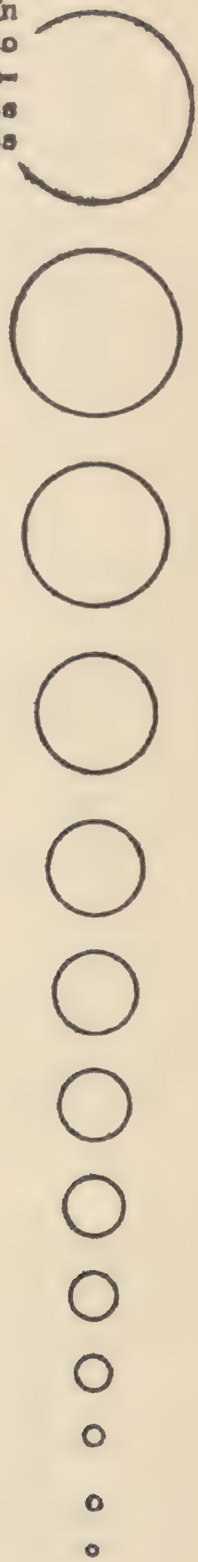
The greatest single factor determining the amount of gas in the intestinal tract is the quality and quantity of food ingested. The following is a list of "Diet Don'ts" for flying personnel, particularly before engaging in high altitude flights:

Don't eat excessively;

Don't eat gas-forming foods, such as beans, cabbage, raw apples, cucumbers, greasy meats, and spice;

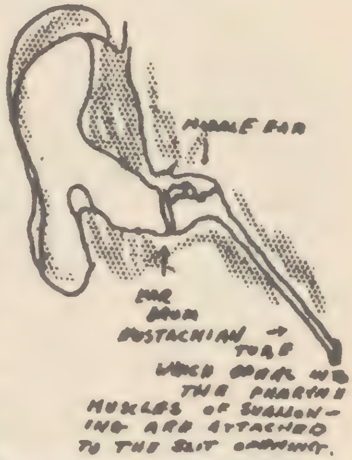
Don't drink carbonated beverages, such as coca colas, gingerale, etc., or whipped drinks, as malted milks, milk shakes, etc.

In mild cases, passage of gas, or descent will ordinarily relieve the distress immediately. In severe cases, it is not unusual for the cramps to last for 24 hours after descent to sea level pressure. Vague, undefined gastro-intestinal complaints have been described as a result of repeated ascents with the attendant abdominal distention.



EAR, NOSE, & SINUS

The nose and the ear are the most frequent sites for disabling symptoms in flying personnel. In order to understand this statement, it is first necessary to understand the fundamental anatomy of the ear, nose, and throat.



Referring to the diagram of the ear, it will be seen that it consists of a series of connecting canals between the side of the head and the back of the throat, or pharynx. If it were not for the tympanic membrane or the ear drum, which lies at the inner end of the external canal, separating it from the middle ear cavity, there would be an open passageway from the external ear to the throat, so that, literally, one could breathe through his ears. It will also be noted that the external canal is large and open to the outside, while the Eustachian tube, which connects the middle ear cavity to the throat, is small. Although the orifice of the Eustachian tube in the throat appears open, it is actually only a closed slit, except when the proper throat muscles are brought into action.

If the atmospheric pressure is decreased, the pressure in the external canal will change more rapidly than in the middle ear. The pressure in the middle ear will be relatively greater and the ear drum will tend to bulge out into the external ear canal. Before the pressure on both sides of the drum can be equalized, some of the air in the middle ear must force itself out through the Eustachian tube and escape into the throat. When this is done the ear drum will return to its normal position. (See diagram, next page)

This process occurs in <u>ascent</u> in aircraft or in the low pressure chamber. Very small changes in pressure will result in a dull or full feeling in the ears. If the individual swallows, or otherwise moves his throat muscles to facilitate passage of air from the middle ear to the throat the ears "pop"; there is no longer that full or dull feeling which means that the ear drum has returned to its normal position. This process is repeated time after time until the ascent is stopped. From a practical standpoint, "clearing the ears", or equalizing the pressure, causes very little trouble on the ascent because the greater pressure

is in the middle ear and it will tend to force the air out through the Eustachian tube, even though no throat movements are made to facilitate it.

On the descent, however, the story is different. If we descend from any given altitude with the ear pressure equalized, the pressure in the external ear will become relatively less. This will force the ear drum inward, toward the middle ear. To equalize the pressure or clear the ears, air must pass through the Eustachian tube into the middle ear. But before this can be done the Eustachian tube orifice in the throat must be opened, and this is done only with voluntary movement of the throat muscles,as swallowing or yawning. Practically, it has been found that if the average, normal individual swallows or yawns about every 300 ft. during descent he will be able to keep the ears clear. It must be emphasized that this is a voluntary action and if it is not carried out the relative pressure between the outside and inside of the drum will become so great that much pain will be caused and a ruptured ear drum may result. The least serious complication is a red, swollen, retracted ear drum, resulting in dull pain and partial deafness for several days. Occasionally gross hemorrhage

occurs into the middle ear, which will also result in temporary deafness, with possible sclerosis of the ossicles and some permanent deficiency in hearing.

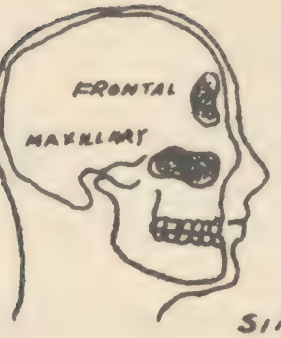
This condition, just described, is called Aero-Otitis Media, to distinguish it from Otitis Media due to bacterial invasion of the middle ear. However, true purulent otitis media may supervene due to the decrease in resistance of the middle ear tissues.

The average normal individual free of upper respiratory infection, with a little experience, can keep his ears "open", even though descending at a very rapid rate. The common cold, however, may be said to be one of the greatest enemies of the aviator. Since, with the common cold there is swelling of the mucous membrane and lymphoid tissue of the throat, the orifice of the Eustachian tube may be involved. The orifice would be narrowed, and thus slower and more difficult to open. In some instances it might be impossible to open.

It is imperative that the flyer with an upper respiratory infection report to the flight surgeon, and the flight surgeon should advise such a man to refrain from flying. It is better to be grounded for two to five days because of a cold than to be grounded indefinitely with damaged ear drums.

An important factor about ear ventilation is the fact that ventilation must be exercised at all altitudes and, as a matter of fact, greater attention must be given it at low altitudes than at high altitudes. This is due to the fact that pressure differentials are greater near the earth's surface than at very high altitude; that is, there is a difference in pressure of 28 mms. of Hg. between sea level and 1000 ft., whereas there is a difference of only 15 mms. between 20 and 21 000 ft.

The paranasal sinuses are air-filled bony cavities lined with mucous membranes, situated within the bones of the anterior skull. There are four sets of sinuses: frontal sinuses (one above each eye in the frontal bones), the maxillary sinuses (antrums, located in the cheek bones), ethmoidal sinuses (located just back of the root of the nose), and the sphenoidal sinuses (posterior to the nose, just beneath the brain). These cavities communicate with the nose through one or more small openings. Under normal conditions with changes in pressure such as occurs in flying from one altitude to another, the passage of air from the cavities takes place with ease. However, if the open-



SINUSES

ings are obstructed by the presence of extraneous tissue or mucus or constricted by inflammatory or allergic swelling, the passage of air is restricted and a pressure differential between the sinuses and the outside air results. This pressure differential will cause sharp, penetrating pain in the sinus region. Peculiarly enough, the pain will occur both when there is negative pressure and when there is positive pressure in the sinuses, so that contrary to the usual situation in ear block great pain may occur both on ascent and descent. This pain is frequently so intensely severe that collapse and unconsciousness occurs.

Again the common cold is one of the most frequent causes of sinus block. The swelling of the mucous membranes which results from the common cold causes closure of the sinus canals. This closure prevents the equilization of sinus pressure with the resultant condition described above.

Here again the aviator must make it his responsibility to seek the advice of the flight surgeon. Temporary grounding may prevent great pain, and possibly serious accident, should the pain cause collapse.

Treatment of ear and sinus block is carried out in the low pressure chamber by spraying the nose and throat with some astringent such as ephedrine, which shrinks the mucous membranes about the orifices of the sinus canals and Eustachian and permits them to open. Upon the advice and direction of the Flight Surgeon, shrinking of the mucous membranes can be accomplished by flying personnel in the course of flight by the use of a Benzedrine Inhaler. However, this should be done only upon the advice of a medical officer. In the event of sudden severe pain, either in flying or in the chamber, instant relief can be obtained by returning to a higher altitude. From there a slower descent should be made.

Closing the mouth and nostrils and blowing, thus increasing the intranasal pressure, will frequently effect relief of both ear and sinus symptoms. This should not be done when other methods such as swallowing, yawning, chewing, yelling, or moving the lower jaw, are adequate.

TEMPERATURE

The temperature range to which aviation personnel may be subjected under present combat conditions may extend from 140° to minus 70° F. Since the production of heat and the regulation of body temperature are essential for normal living, aviation personnel must concern itself with the environmental temperature.

Heat is produced in the body as the result of oxidation of foods. Any exercise, even the slightest physical exertion, increases the production of heat above a resting rate. Ingestion of food will increase the production of heat, and the absorption of heat from exposure to the sun's rays may increase basal heat production two- or threefold. These various mechanisms of producing heat are considered the chemical regulation of heat control. The loss of heat usually occurs through physical means, such as radiation, conviction, and conduction. The regulation of body temperature to approximately 98.6° F. under a variety of environmental conditions is done by the balancing of heat production with heat loss. The proper use of clothing is man's main method for controlling heat loss. Because of this and because of the wide range of temperatures encountered in aviation, adequate clothing for flying personnel is an important consideration.

An added consideration must be made in regard to high altitudes, since as the altitude increases the temperature decreases. This decrease in environmental temperature provokes an increased effort on the body toward heat production and this, in turn, demands a greater amount of oxygen. We see here the beginning of what can become a vicious circle, wherein the body reaches higher and higher altitudes and demands more and more oxygen for maintaining its temperature and at the same time enters an environment which has a decreasing partial pressure of oxygen. Shivering, which is an involuntary muscular exercise for increasing heat production, is effective, and at sea level causes no great demands upon the respiratory system. At an altitude of 35 000 ft., however, the additional muscular activity of shivering causes a great drain on the already limited supply of oxygen and can precipitate anoxic failure.

Protection from cold in aircraft depends upon the flying conditions and the aircraft. Fighter planes usually present no great problem since the cockpit of most fighters is close to the engine, Large crew aircraft, where various

members of the crew have battle stations distant from the heated pilot cabin, call for special clothing. Recent developments include electrically-heated flying suits which are lightweight and of little bulk so that wearers can fit into small, cramped spaces which are isolated from the main section of the aircraft and by plugging their line into the power supply of the plane, can maintain a comfortable temperature. Protection must be given to the exposed parts of the face to prevent frostbite; this can be accomplished by use of protective salves. The eyes can be protected by the use of adequate goggles.

The environmental temperature, especially that of high altitudes, must be taken into account in the use of oxygen equipment. Caution must be exercised and constant checking carried out in order to avoid freezing of equipment, particularly since expired breath is always vapor-charged.

AIRSICKNESS

Air sickness is comparable to sea sickness. The causes are much the same in both cases. The symptoms are sweating, nausea, vomiting, often accompanied by dizziness, lassitude, depression. There is a great variation in the symptoms of different individuals. Some may get relief from vomiting; others may be depressed and nauseated without vomiting; some turn green; in general, the disease is very uncomfortable and incapacitating. History has usually smiled at the ailing sea sick or air sick person and there has been much bravado on the part of those who at that particular moment are not suffering. Yet it is doubtful that there is any person who has never experienced a certain amount of air sickness or sea sickness. There are also some persons who are particularly sensitive to any changes in position and are chronic sufferers. Most persons, however, can usually overcome the bodily reaction s to motion by learning certain tricks in orientation, such as visual concentration on the horizon or some fixed spot in the horizon, and by developing confidence in themselves that they will be able to withstand combinations of unfavorable sensations by keeping themselves fit and occupied. Dietary indulgences, smoking excess, lack of adequate bodily care, are conducive to lowering the tolerance of the individual to air sickness. To avoid air sickness it i s advised to maintain a moderately full stomach, to fix visual concentration on some point in the horizon, and to maintain adequate ventilation.

Foul odors, especially those of hot oil, gasoline, and warmed rubber, which are common in aircraft, and the presence of noxious gases, particularly very small amounts of carbon monoxide, coupled with relative lack of oxygen which begins to manifest itself above 8 000 ft., are conducive to air sickness.

FATIGUE

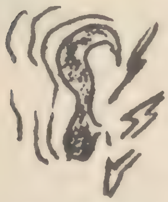
Fatigue is a generalized condition of the body organism due to excessive strain, coupled with inadequate recuperation. It is a condition which involves each and every part of the body organism, and, although some particular system, such as the nervous system, gastro-intestinal system, or the muscular system, may show more evidence of fatigue than others, it must be understood that it is a disease of the entire body. The condition is associated with weariness, inefficiency, weakness, disinclination to continue work, nervousness, and irritability. The condition also produces an intense demand for rest. The best example can be seen in cases of marked muscular fatigue after prolonged exercise or physical exertion, when the body's urgent need for rest in order to repair and rebuild exhausted and broken-down parts of the body causes the subject great weariness, unto sleep. Fatigue is also associated with emotiohs, so that the degree of fatigue can be greater than one would expect from the sheer physical exertion involved in flying. In other words, the emotional tension and strain of combat flying can play an important role in provoking fatigue, even though the subject has done relatively little physical exertion.

The fatigue of flying personnel is occupational in character. This fatigue, which is a generalized bodily fatigue, is incurred by the emotional stress, mental effort, and various amounts of physical activity experienced in flying. Combat flying is much more fatiguing than routine flying by virtue of the increased emotional duress and mental efforts involved and also the greater amount of physical activity demanded. Prior to the war, flight personnel rarely engaged in prolonged flights, and an average service pilot spent approximately 300 hours a year in the air. Under these conditions fatigue among flight personnel was not a pressing problem. Today, however, when flights of 20 hours or longer are common, and aviators may spend as many as 200 hours a month in the air, the condition of aviation fatigue is an important one. There are certain conditions encountered in aviation which are conducive to fatigue.

The emotional stresses associated with flying, particularly under combat conditions, cannot be minimized in considering psycho-somatic reactions which result in conditions such as nervousness, anxiety, and fear. The amount of emotional stress is in part dependent upon the psychic make-up of the individual and depends upon the type of flying, whether combat or patrol, day or night, in good or bad

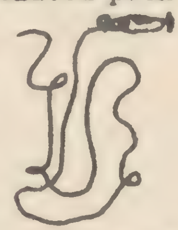
weather. The pilot, having the responsibility of command in control of the airplane and being more acutely aware of flight conditions, is more apt to suffer in this respect than the rest of the crew. Intense mental concentration is required of the pilot during the entire course of the flight and most of the cranial nerves are stimulated to an unusual degree. The eyes are in constant motion, continually roving the instrument panel and exploring the horizon. Accommodation is frequently shifted as the pilot views the panel, terrain, and maps, and, in general, the concentration effort demanded of the pilot and also the rest of the crew is beyond that found in almost any other routine work.

Noise and vibration in aircraft effect the impact of sound and tactile impulses upon the sensory nerve endings in the body and provoke and stimulate the nervous system to a marked degree. Although at first glance the noise and vibration of aircraft may appear to be of relatively little

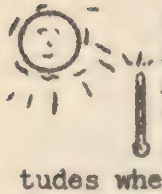


importance, careful evaluation of these constant high grade stimuli reveals a very marked contributing factor in the development of fatigue. Aircraft comfortization, which includes adequate ventilation, proper air-conditioning, reduction of vibration and noise, has done a great deal for the reduction of these provocative conditions in peace time commercial aircraft, but in service craft this degree of comfortization cannot be achieved.

The spatial changes in aircraft are constantly setting up impulses which result in stimulation of the nerves of equilibration. The many impulses which are constantly sent to the brain and relayed to the muscles by associated pathways and which result in muscular reactions, all tend to induce bodily fatigue. Minor shifts of the viscera within the abdominal cavity caused by postural changes also result in the elicitation of many stimuli from that region to the brain. The magnitude, complexity, and constancy of these stimuli in flight by far exceed those encountered in normal terrestrial existence.



The rapid temperature changes associated with present-day flying, ranging up to and over 100° F., are also conducive to fatigue. The fact that the air temperature changes roughly 2 C. degrees per thousand feet of altitude accounts for a very marked and severe change of the body environment



in regard to temperature change, in turn causing many bodily reactions which tend to compensate and maintain an even temperature equilibrium. Wearing very heavy flying gear at ground level in tropical or semi-tropical regions and then going to altitudes where even this heavy flying gear is not completely protective, subjects the body to such extremes that fatigue is inevitable.

Ventilation usually is not within the comfort zone in aircraft. The lack of adequate ventilation results in the presence of unusual odors, gasoline, oil, rubber, etc., which may be deleterious to the health and sometimes are quite nauseating. The presence of noxious gases, particularly carbon monoxide, is always a potential danger, and even though the concentration of gas present may be subminimal, prolonged breathing of contaminated air is harmful.

Anoxia is a special aspect of improper ventilation, chiefly inadequacy of oxygen, and although the use of oxygen masks is directed by the Bureau there are many occasions in practice when personnel permit themselves to fly at altitudes which result in a low grade anoxia. This low grade anoxia reduces the capacity of the body tissue for natural, normal repair with resultant accumulation of broken-down tissues and metabolic waste products. It is also true that in altitudes over 33 000 feet, even with pure oxygen supply, there is a degree of anoxia.

Continued fatigue in flight personnel may result in a condition known as staleness. In this condition men are emotionally and physically unfit for active flying. Any number of symptoms are present: excessive fatigue, increased irritability, loss of appetite, digestive disturbances with loss of weight, insomnia, nightmares, weariness, etc.

The best treatment of staleness and also of fatigue is a preventime treatment. This means that the flying time of aviation personnel should be limited within a given length of time; it means that bodily comfort, rest, and recreation between missions should be stimulated and promoted; it means further, keeping the body in optimal condition of physical fitness, and it also means relieving as far as possible various extraneous causes for emotional difficulties and conflicts, such as worry over economic conditions, over the safety of the family and loved ones at home, etc.

In summary it can be said that fatigue in flying personnel is a generalized body condition resulting from pro-

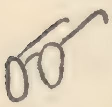
longed over-stimulation, either high grade or low grade, of the body and its various parts, and a lack of adequate period of rest and recuperation between these periods of provocation. Moreover, the best method for the handling of aviation fatigue is the understanding of the condition as a generalized condition and the removal or reduction, to as great a degree as possible, of the various provocative factors which produce fatigue. It is particularly important to realize the preventive aspects in the treatment of staleness and fatigue, since it has become a costly lesson that when fatigue is permitted to exist for too long a period of time the damage becomes irreparable and flying personnel suffer nervous "break-downs", which makes them unfit for service activity for a very long period of time, if not for ever.

BODILY CARE

Flying personnel must pay particular attention to maintaining their bodies in the best physical condition. A flyer in an open airship is exposed to wind which, even at moderate altitudes, is colder than that at the earths surface, and drier; it tends to make the eyes water, dry and chap the skin, and cool the body. Goggles should be worn, helmets should be worn, and gloves should be worn. Exposed parts of the body can be protected partially by an application of cold cream or lanolin. Drafts should be avoided as much as possible in closed cockpits.

The decrease of air temperatures with progressive increase in altitude results in constant lowering of the temperature of the environment of aviation personnel as they climb into the higher heights. When the skin becomes cold, nerve messages fleeing to the centers which regulate the body temperature excite the bodily mechanism for increased warmth, with a resultant increased use of oxygen. This is an important factor to realize in the course of high altitude flying. Furthermore, cold, when it becomes increased enough, influences bodily movements, makes the flyer particularly uncomfortable, and disturbs his concentration. Frostbites and freezing to death can occur unless adequate protection is taken. Adequate protection consists chiefly of the proper clothing and proper heating. If flying must take place in cold climates then oxygen should be used at altitudes lower than the customary 10 000 ft.

Aviation personnel must be particularly careful in protection of the eyes and ears. For the protection of the eyes, properly fitted regulation goggles offer all that is necessary. These goggles should be tinted for use in aircraft at sea, over snow country, and over deserts. The proper care of the eyes in night flying is not only of importance to the pilot as an individual, but of utmost importance in combat activity, since eyes which have become adapted to darkness and are keen in perceiving very fine differences in gray tones are extremely sensitive to light and a sudden glare of a search light, or even a misdirected landing field light can blind a pilot with serious results.



The protection of the ears from the constant drumming, vibrating noises, at various pitches and volume, which are part of aircraft, is important for two reasons. First, keen hearing is of help in detecting smooth function of the engines and also for adequate communication over the intercommunication system. The second is in regard to sound and fatigue. When the pilot is protected from sound and noise he is removing an element which plays a rather marked role in provoking pilot fatigue.

General bodily condition, the maintenance of physical fitness is of obvious value. The aviation crew in its ordinary routine work does not do much physical exercise, and yet the maintaining of maximum bodily fitness is of prime importance because it permits them to better withstand the tiring effects of flying.

Adequate relaxed rest should be cherished by the air crew, since it is this period when the bodily tissues, muscles, nerves, etc., hage an opportunity to repair and rejuvenate. Rest includes not only sleep but also moderate relaxing recreation, congenial comradeship, and interest in some activity, preferably something beyond and outside the scope of aviation.

CARBON MONOXIDE

The aviation industry, the flying, manufacturing, and servicing of aircraft, has hazards caused by the use and presence of harmful substances, such as dopes, paints, cleaning material, aviation gasoline, exhaust gases, hot oil fumes, fire extinguishing compounds, etc. The properly trained aviation medicine technician and barochamber technician should acquaint himself with the various noxious gases and learn precautions necessary in the handling and use of these substances.

Airplane dope consists of various materials used on fabric coverings of airplanes. Fumes of these substances are irritating to the nose and throat and skin, and some are particularly dangerous, since very small percentages produce marked symptoms, as anemia and bleeding into the skin. The best precaution to take against dopes is the proper ventilation of shops, use of adequate masks, and frequent periods of recesses in the outdoors. There is also great danger in doperooms of the possibility of fire, since many compounds are highly inflammable. All flames and electrical sparking devices should be eliminated. The spraying of paint lacquer and dope is a very common procedure around aircraft, particularly sea craft, and persons engaged in this should be extremely careful and should wear respirators.

Cleaning materials in aircraft shops can be (2) aqueous, or watery, cleaners, and (b) volatile cleaners. The aqueous cleaners consist of soaps, cleaner and polisher, (neither of which is dangerous) and platers cleaner, heavy duty cleaner, aluminum cleaning compouns, carbon remover, phosphoric acid alcohol cleaner, which are all very irritant to the skin and from which there is a danger of severe burns to the skin and eyes. Precautions against contact must, therefore, be carefully exercised. The volatile cleaners are: gasoline, benzine, acetone, paint and varnish remover, alcohol, dry cleaning solvent, and carbon tetrachloride. All except the last are highly inflammable and great caution must be used in regard to heat and flame. They are more or less toxic and their detrimental effects occur through absorption through the skin or through inhalation. Breathing the vapors or spilling the liquid on clothing or exposed parts must be avoided. Carbon tetrachloride must not be allowed to come in contact with hot metal, since by heating it phosgene is generated and phosgene is extremely poisonous.

In addition to the usual dangers of ordinary gasoline, aviation gasoline contains an added substance, ethyl fluid (tetra ethyl lead), which is very toxic. The fumes of this fluid can cause unconsciousness and death; good ventilation is, therefore, essential. Intense heat (the desert sun, for example) can "boil over" motor gasoline. Then, when the plane starts up, the fumes can rapidly overcome the pilot. If desert conditions are encountered the safest thing is to wear an oxygen mask for several minutes after the take-off. Rubber gloves should be worn in handling the fluid, as the pure ethyl fluid can burn. If it does contact the skin, wash thoroughly with soap and water immediately.

The principal compounds used in fire extinguishers in or about aircraft, are carbon dioxide and carbon tetrachloride. Carbon dioxide gas is non-combustible. High concentration of carbon dioxide depresses the respiratory rate and can result in death. Carbon tetrachloride is a poisonous volatile liquid and when inhaled it acts as an anesthetic, causing drowsiness, dizziness, headache, excitement, vomiting, anesthesia, and finally unconsciousness.

If carbon tetrachloride, which has a characteristic odor, is detected in flight, the source should be checked and eliminated immediately and the cockpit ventilated.

When sprayed on a fire or on hot metal, carbon tetrachloride forms phosgene, a poisonous gas. Since inhalation of even a few "whiffs" of this gas may be fatal it must be avoided. Crash crews are equipped with gas masks for this purpose. At the scene of an aircraft fire, whenever crash crews start spraying, get leeward of the fire.

Exhaust gases from internal combustion engines used in aircraft usually contain methane, hydrogen, oxygen, carbon monoxide, carbon dioxide, and nitrogen. In addition, airplane engines using ethyl gasoline will blow little solid particles out with the exhaust gases. These consist mainly of lead chloride, lead sulfate, and carbon particles.

Certain of these above mentioned products are toxic if inhaled by flying personnel, and if the cockpit or cabin air is contaminated by them they should be removed to avoid serious effects.

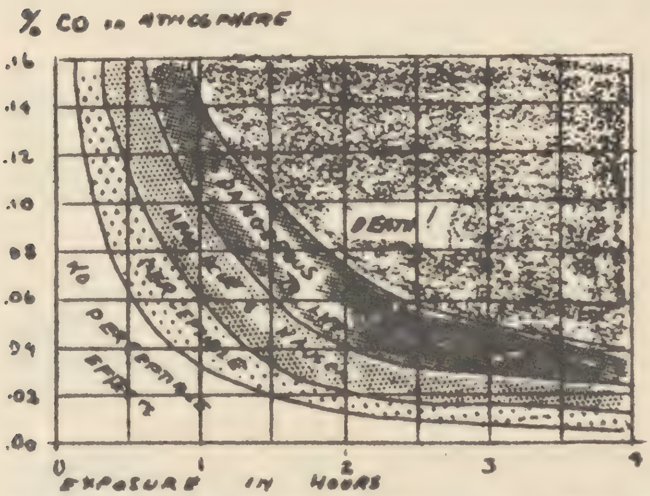
There are several factors concerned in the elimination of exhaust products from the interiors of airplanes. One of the most important of these is whether the engine is directly in front of the fuselage, as in single- or tri-motored

aircraft. Little trouble has been encountered with 2 or 4 motored airplanes. Where an engine is immediately in front of the personnel compartment, the amount of exhaust gas entering it depends largely on the motor exhaust system.

To be absolutely certain that exhaust fumes are not getting into cockpit or cabin is to analyze the air in these places.

The greatest potential danger from noxious gases in aircraft comes from the exhaust carbon monoxide. It is a tasteless and <u>odorless</u> gas. It occurs in exhaust fumes from the incomplete combustion of carbon materials. The amount of carbon monoxide in exhaust gases varies from 1 to 7%, with an average of 2.8%. However, the carbon monoxide of the exhaust becomes well mixed with atmospheric air before reaching the cockpit of an airplane and seldom exceeds a concentration of .04% at that point. Nevertheless, even this small amount is known to be highly toxic.

Carbon monoxide is dangerous because it produces an anoxia by diminishing the oxygen-carrying capacity of the blood. The attraction of hemoglobin for carbon monoxide is 300 times as great as for oxygen, so that in a mixture of hemoglobin, oxygen, and carbon monoxide, the carbon monoxide's chances of combining with ~~the hemoglobin~~ are 300 times better than those of the oxygen. Moreover, the carbon monoxide already present in the arterial blood acts to further increase the anoxia by preventing the release of oxygen from the blood to the tissues. Since the blood oxygen saturation is low at high altitudes, and since even a very small amount of carbon monoxide reduces the oxygen-carrying capacity of the blood, the danger of even traces of carbon monoxide at high altitudes is great For Example, at 14 000 feet, the arterial oxygen saturation is 18%



and signs of anoxia may develop; if .005% carbon monoxide is present, signs of anoxia may develop at 11 600 feet,

and if .01% carbon monoxide is present, signs of anoxia may develop at 7 000 feet. The table shows the correlation of carbon monoxide concentration in the blood with the signs and symptoms of carbon monoxide poisoning. (Use chart for relation of blood carbon monoxide and atmospheric carbon monoxide)

Carbon Monoxide, percent in blood	Symptoms
0-10	None
10-20	Tightness across forehead, possibly slight headache, dilatation of cutaneous blood vessels.
20-30	Headache, throbbing in temples.
30-40	Severe headache, weakness, dizziness, dimness of vision, nausea, and vomiting, and collapse.
40-50	Same as previous, with increased pulse rate and respiration, and more possibility of collapse.
50-60	Syncope, increased respiration and pulse, coma with intermittent convulsions, Cheyne-Stokes' type of respiration.
60-70	Coma, with intermittent convulsions, depressed heart action - possibly death.
70-80	Weak pulse and slowed respiration, respiratory failure and death.

Since carbon monoxide poisoning comes on so insidiously and since it is as dangerous as it is, preventive measures to keep it out of the cabins and cockpits of planes must be used. In order to control the carbon monoxide problem it is necessary to establish the allowable concentration of gas which is harmless and which can be measured by a practical method. The use of the Mines Safety Appliance Company Indicator, which can measure as low as 0.003%, is an essential part of the preventive measures against carbon monoxide poisoning. All airplanes should be tested with this indicator, with readings taken at different altitudes, with different throttle and fuel mixture settings, and with various cabin and ventilator openings. If any change in plane design is made, new tests are necessary.

DANGEROUS CONCENTRATIONS OF CARBON MONOXIDE

Concentration, percent	Effect
0.01, or 1 part in 10 000	No symptoms for 2 hours
0.04, or 4 parts in 10 000	No symptoms for 1 hour
0.06 to 0.07, or 6 to 7 parts in 10 000	Headache and unpleasant symptoms in 1 hour
0.10 to 0.12, or 10 to 12 parts in 10 000	Dangerour for 1 hour
0.35 or 35 parts in 10 000	Fatal in less than 1 hour

Dangerous concentrations of carbon monoxide in aircraft compartments are indicated by:

1. Subjective symptoms, such as throbbing headache, nausea, dizziness or dimming of vision.

2. Odor of exhaust gases.

3. Sounding of a warning signal.

Required action is as follows:

1. Open all cockpit hoods or windows and attempt to eliminate any odor of exhaust fumes by ventilation.

2. Attach oxygen masks and breathe pure oxygen until the symptoms disappear.

3. Descend to lower altitude as soon as possible.

4. Turn off exhaust heaters if such are in use.

The treatment for carbon monoxide poisoning is the breathing of 95% oxygen with 5% carbon dioxide.

NIGHT VISION

Night vision is of special importance in military operations and since the mechanism differs from that of day vision we will consider some aspects of it.

The main difference between night vision and day vision, is that night vision is accomplished with the peripheral field of vision, whereas day vision is central. The factors which affect night vision are dark adaptation, altitude, food, and individual variations. Dark adaptation is a chemical process within the retinal cells by which the visual sensitivity is improved almost ten thousandfold after a period of 30 minutes of darkness. A fraction of a second of full light can destroy the entire sensitivity increase which has been gained by the 30-minute darkness. Even small amounts of dial light can reduce the dark adaptation. It has been found that red-lensed goggles assist in dark adapting and in maintaining dark adaptation.

Altitude plays a very important role in night vision. The sensitivity of the retinal cells and brain cells controlling vision to oxygen lack is very acute and even the moderately low altitudes at reduced partial pressure of oxygen with the resultant reduced tissue oxygen can interfere with night vision. For this reason Technical Order of the Bureau of Aeronautics states that in all night flying, regardless of altitude, accessory oxygen should be used.

A chemical factor in the diet, Vitamin A, is also essential for adequate night vision. An excess of this vitamin will not increase visual acuity, but any decrease from the normal amount will seriously influence night vision. In combat zones where probabilities exist for reduced rations, it is particularly important that flying personnel be supplied with adequate Vitamin A.

Individual variation in regard to night vision is great and persons with keen vision can see as well with one-tenth the illumination as those with poorest night vision. The individual can improve his own night vision by practicing peripheral seeing, that is, practicing to look through the side of his eyes rather than head-on. This can be done out of doors at night.

In summary, the following suggestions can be made for improving the efficiency of night vision:

1. Developing dark adaptation prior to any night flights and maintaining that adaptation.

2. Eliminating all non-essential lights within the aircraft and keeping essential ones very dim.

3. Using red light in aircraft wherever possible.

4. Using especially prepared charts and maps which can be visualized in red light.

5. Using supplemental oxygen at all altitudes.

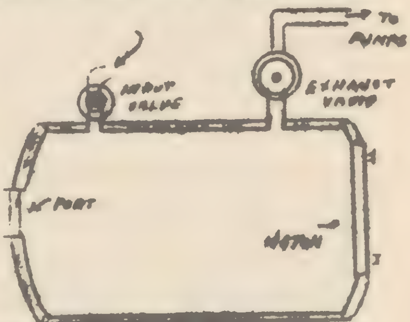
6. Guarding against Vitamin A deficiency.

7. Practicing peripheral vision.

BAROCHAMBER : THEORY

Whenever the scientist or the engineer wishes to study the behavior of some machine or some substance under a particular condition, he builds an artificial environment and places the machine within that environment. To study the behavior of certain types of airfoils or wing structures of aircraft, the aeronautical engineer studies the new design of wing in an air tunnel. In this way he can subject the design to conditions of flight without going through the complete process of building a plane, and then flying it. As a matter of fact, the short-cut method of the wind tunnel also affords a much greater opportunity for careful and controlled study. To study the behavior of an engine in polar regions, the engineer places the engine in a refrigerated chamber and studies its performance.

The low pressure chamber is a device by which the scientist can make artificial conditions which are similar to the conditions of the atmosphere. Not all conditions of the atmosphere can be simulated in the chamber, but as far as man's behavior is concerned three very important conditions can be made. The low pressure chamber can be used to make artificial altitude conditions insofar as the pressure, the partial pressure of gases, and, in chill chambers, the temperature of the atmosphere are concerned. By making high altitude conditions within a confined chamber on the ground level the reactions of man to high altitude can be studied and demonstrated on humans without the use of aircraft and without all the attendant difficulty and risk which is incurred in high altitude flying. Moreover, the use of the chamber permits a greater control of simulated altitudes and rates of ascent and descent.



Another important factor about the low pressure chamber is the convenience with which subjects can be observed from the outside of the chamber. This does not pertain only to the seeing of the subjects through ports, and the speaking with them over the intercommunication system, but also to the use of measuring devices, such as electrocardiographs, photoelectric hemoglobinometers, which can be attached to the subjects inside the chamber and read and recorded by outside observers.

The essential structure of the low pressure chamber is a reinforced substantial structure which can be sealed from the outside air. By an arrangement of a vacuum, or suction pump, the air inside the chamber is removed at a rate comparable to any desired rate of climb. An intake valve is always kept open so that there is a constant flow of fresh air into the chamber, and no foul air (contaminated with carbon dioxide from expired breath) is allowed to accumulate. By adjustment of the intake and exhaust valves, the internal pressure of the chamber can be "set" at any desired pressure (altitude), and in this way high altitudes can be simulated at ground level.

It is clear then that with the use of the low pressure chamber it is possible to study certain reactions of the human being under conditions of high altitudes (low atmospheric pressure) without leaving the ground. These special bodily reactions are those concerned directly with pressure changes and the changes in body cavities and body-contained air, and with the partial pressure changes of oxygen in regard to the metabolism (tissue·energy exchanges). The low pressure chamber affords an opportunity to study and experience the influence of decreased pressure and of decreased oxygen, or oxygen lack.

It is an established fact that with the increase in altitude the atmospheric temperature decreases, and at an approximate rate of one degree (centigrade) to every five hundred feet increment in altitude. Low pressure chambers have been developed with proper refrigerating systems so that with simulated altitude changes parallel temperature changes are introduced. This type of low pressure chamber is called a chill-chamber. The use of this chill-chamber affords an opportunity to study, not only the pressure and oxygen changes, but also the temperature changes.

BAROCHAMBER: OPERATION

The operation of the barochamber (low pressure chamber) is one of the important responsibilities and duties of the technician. The carrying out of this duty should be focused through three frames of reference. First, the focus of the teacher. In other words, the barochamber is primarily a teaching device and all the operation and activity of such a unit should emphasize training and teaching aspects of the simulated flights. The second focus or point of view should be that of the doctor, which means every effort should be made toward keeping men in maximum flying fitness. The doctor is concerned with maintaining the barochamber as an estimate for aiding understanding of the body so that maximum physical fitness can be achieved by flying personnel. The third point of view is the engineer. The barochamber and its related equipment, oxygen equipment, pressure systems, pump systems, and communication system, is a highly technicological unit and its proper operation and understanding demands the engineer's point of view in regard to handling of the equipment and maintaining it, and a knowledge of its function.

Detailed aspects of the operations of the various parts of the barochamber are, of course, dependent upon the specific equipment of the particular barochamber. The pump system is the system by which air is evacuated from the chamber at a rate to simulate various rates of climb, up to 6, 7, and 8 000 ft. per minute. The pumps are vacuum pumps and may be water or oil-sealed. Detailed and specific operational procedures must be mastered for each type of pump.

The communication system is usually an electronic intercommunication system, so that observers and subjects inside the chamber can maintain contact with observers outside. The operation of these units is usually very simple and consists principally of seeing that adequate connections are made, that switches are in their proper position, and that various volume controls are set.

Oxygen equipment and oxygen supply obviously play an essential role in the operation of a barochamber, and a complete understanding of the nature and operation of the equipment is invaluable to the technician. The oxygen equipment used in the chamber is used not only to afford a supply of oxygen in case of emergency or to give adequate oxygen to maintain life at the higher altitudes, but also

IT IS USED IN THE BAROCHAMBER FOR TRAINING PURPOSES. To that end the technician must know the Navy equipment so that he may assist in the teaching of this equipment to the trainees and guide them in the course of routine runs. The more expert his understanding and teaching, the greater his value to the service.

Medical equipment involved in the operation of the barochamber consists of equipment used in the examination of nasal passages and ears and equipment used for shrinking mucous membranes of the sinuses so that sinus and middle ear ventilation can be expedited. There is also First Aid equipment, primarily stimulants which may be needed on occasion for resuscitation. The use and care of medical equipment follows the dictates of the use and care of all medical equipment in the hospital corps. Another medical aspect is the proper care of face masks. Since many men use the same face mask during the course of the day it is essential that the facepiece be sterilized after each use in order to avoid transmission of upper respiratory infections.

The teacher's point of view is a very important one in the operation of the barochamber, and the proper understanding and incorporation of this point of view results in treating the barochamber as a school. As such, every effort is made for the exhibiting of educational charts and diagrams, cutaway models of equipment, and having available various bulletins on aviation hygiene. The operation of the barochamber usually elicits a great deal of inquiry from the trainees and from the casual spectators and the technician can render aviation hygiene a particular service in emphasizing and reiterating that the fundamental function of the operation of the barochamber is for the training of aviation personnel in the various aspects of aviation hygiene, including the effects of anoxia, measures for avoiding anoxia, middle ear ventilation, bends, etc.

Technicians assigned to duty at barochambers may be given any one of a number of assignments. The particular type of assignment will, of course, depend upon the unit. In general, however, the duties can be classified as (1) general duties about the chamber, and (2) specific duties, such as controls operator, inside observer, outside observer, recorder, equipment demonstrator, etc.

In carrying out the general duties, the technician can find no better pattern than that stated under the theory and maintenance of a barochamber namely, that the ac-

tivity should function as a training or teaching unit with the additional point of view of the medical officer and the engineer. The general duties around a barochamber, then, as the general duties in any unit in the Navy, call for military precision and exactness and dispatch.

Specific duties relating to the barochamber as a teaching unit can be better visualized by taking each post separately.

In order to be a better teaching service to the trainees and also in order to have present someone who has adequate medical training, to take care of any medical emergency at a high altitude in the chamber, the general procedure is to have a trained technician or a medical officer participate as an inside observer in each flight of the barochamber. The duties and responsibilities of the inside observers are rather clearly defined by the procedure of the run. At the present time this procedure consists of, first, an ear check, that is, a preliminary short flight to a certain altitude with drop to sea level during which the trainees are given an opportunity to demonstrate their capacity to ventilate their middle ears. This is followed by preparations for a routine indoctrination flight, which consists of taking sea level pulses and giving a mental acuity test to the trainees at sea level. Following these two procedures it is the custom to demonstrate again the oxygen equipment and to permit the trainees to go through check-lists for the use of their equipment. The flight gets under way, and the group climbs to an altitude of 18 000 ft., where the flight is levelled off. A 10-minute stay is carried out, during which time the inside observer pays particular attention to all the signs and symptoms of the trainees and is on guard in case any trainee collapses or faints because of lack of adequate oxygen. A good inside observer points out to the trainees the various anoxic changes that they are experiencing or that can be seen in fellow crew members. At the end of a 5-minute interval at 18 000 ft. pulses are taken and a check is made for gross tolerance. After the group has stayed at 18 000 ft. for 10 minutes it is given a second mental acuity test. At the completion of this test, which usually takes three minutes, the inside observer tells the men to put on their oxygen masks and assists those who need help. The observer then checks all the face pieces for fitness, he carries out a drill in the flushing-out of the rebreather equipment, and when he has satisfied himself that all men have returned to a normal state and that each has an adequate and properly functioning oxygen supply, he signals the controls operator to climb to an altitude of 28 000 ft.

At this altitude the observer is particularly alert regarding the possibilities of men's lapsing into unconsciousness for lack of oxygen which may occur because of equipment failure, ill-fitting masks, etc. A third mental acuity test is taken at this altitude, pulses are taken, and the chamber begins to descend.

The descent embodies an important responsibility for the inside observer and that is to see to it that the crew members make the necessary effort for ventilating their middle ears. On those occasions when a crew member experiences an ear block, the inside observer arranges for levelling-off of the chamber or increasing its altitude and advises and assists the trainee in overcoming his block.

During the course of the flight and in its return a good inside observer continues emphasizing the fact that all that has happened in the chamber is for training. The tests and the pulse rates are taken not to test a man but to show him that regardless of his zeal or desire under a slight degree of anoxia his performance is definitely poor and with oxygen at an altitude just under two miles his performance cannot be differentiated from that at sea level.

The controls operator is the pilot, so to speak, of the barochamber, and by adequate handling of the intake and exhaust valves which connect the chamber to the pump the operator can maintain any flight path in regard to altitude climb and descent which he wishes. Controls operators should learn and understand the nature of the equipment, the panel board which he uses for controlling the flight, namely the altimeter, the rate of climb meter, and the clock. The controls operator is also responsible for seeing that the communication system is intact and in working order, and also that the water and power for pump systems are in order.

The proper and adequate keeping of records in the barochamber cannot be overemphasized. The accurate keeping of records not only affords the unit an index of its activity but affords opportunity for the unit to examine critically its training program, to study the various conditions encountered in routine flights so that the staff can revise or control its program with maximum effectiveness.

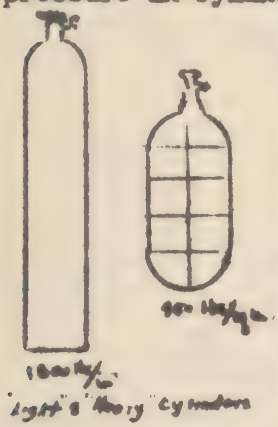
OXYGEN EQUIPMENT

The following notes are presented for instruction and guidance in demonstrating oxygen breathing equipment to Navy personnel and are presented in the form of a lecture to the trainees in aviation hygiene.

This part of your short course in Aviation Hygiene deals with standard Navy Oxygen Equipment, and its proper use. It is of great importance for you to learn how to use this equipment properly, to understand how it works, and to practice its use so that you will become familiar with its use and feel comfortable while you are using it. The information regarding oxygen equipment which you are about to hear, and the Bureau of Aeronautics Technical Order 42-40, which has been given you and which you will find reprinted on the back of the small certificate which you will receive at the completion of your short course in Aviation Hygiene, are the two most vital and essential phases of Aviation Hygiene.

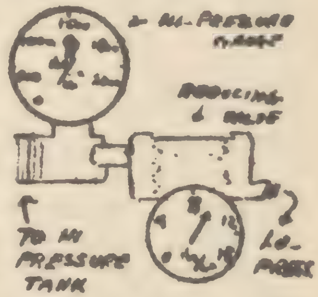
Standard Navy Oxygen Equipment can be classified into four types. By good fortune each type is named in accordance with the method by which it operates, and we discuss all four, although the occasion may not arise for the use of all, in order that you may appreciate the development of the equipment and also that you may better understand the latest models.

In the first place, we must understand that oxygen as used in the Navy comes to us in a gas form under high pressure in cylinders or oxygen bottles which are heavily



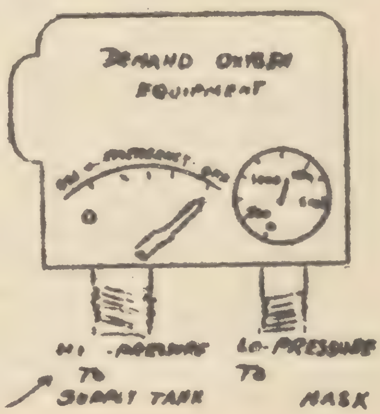
walled metal cylinders containing oxygen under a head of 1800 lbs. pressure per square inch. The use of oxygen directly from such a bottle would result in damage and irritation of the nose and of the mouth because of its high pressure. Therefore, it is necessary in all types of equipment to have a mechanism by which the pressure is reduced from 1800 lbs. to from 9 to 12 or 15 lbs. The device used for lowering the pressure is called a "reduction valve". There are various types of reduction valves. Some are separate from the rest of the equipment and others are incorporated within it.

The earliest type of oxygen equipment, both insofar as its use and its development is concerned is the <u>Constant Flow</u>. This functions exactly as it is named, and the user of oxygen has a continuous and constant flow of oxygen from the oxygen source to his breathing apparatus. Of course, there is a reducing valve in the line.



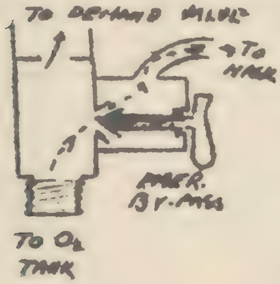
The Constant Flow in its primitive form consisted of an oxygen bottle, a reducing valve, a rubber hose connection, and a mouthpiece which appeared similar to an ordinary pipestem. The user inserted the pipestem in the corner of his mouth and with a certain amount of practice was able to suck in air through one corner of his mouth and breathe out his breath through the other. Beyond the fact that this system was simple and supplied oxygen it had no virtues and all vices. It was uncomfortable to use, because it would irritate the tissue membrane and produce marked salivation (incidentally, it was given the name of "The Drool Tool" by old aviators). At high altitudes it would freeze. It took a great deal of training to learn to use it with even a small amount of efficiency. It was fundamentally inefficient. It was tiring for the jaws of the user, and on those occasions when the pipe stem slipped from the mouth of the user it often became quite a task to fumble and fish around with heavy gloves for this fine rubber tubing and pipestem. Moreover, it was very wasteful insofar as the use of oxygen was concerned, for oxygen was being discharged whether the user was breathing in or breathing out.

In order to have a more efficient apparatus, a second type, the <u>Demand Regulator</u> type, was designed, which delivers oxygen from a cylinder through a reducing valve to the user at rates automatically adjus-ted to the demand. In other words when the user inhales and demands oxygen he gets oxygen, and when he exhales and has no need for oxygen no oxygen flows from the system. The operation of this instrument is controlled by a small suction which is developed as one inhales. Oxygen is inspired from the cylinder and the exhaled air is exhausted to the atmosphere. The apparatus consists of a regulator, a facepiece, and a breathing hose.

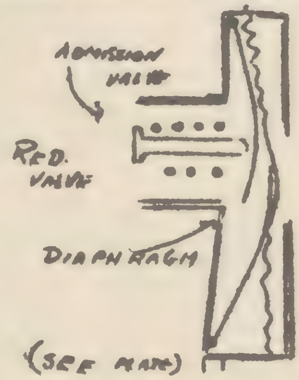


These are connected to the oxygen cylinder. The reducing valve is incorporated in the assembly and also a gauge, graduated per square inch, is installed on the regulator. The facepiece has two small exhalation vents which permit expelling air but prevent atmospheric air from entering into the breathing circuit on inspiration.

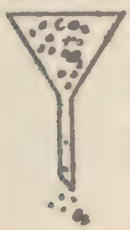
There is a manually operated "Emergency Bypass Valve", which permits the user to convert the demand apparatus into a constant flow type in case the regulator fails to operate properly and automatically. It is important to realize that when the user opens the bypass valve the consumption of oxygen will be greatly increased and his supply bottle will last for a much shorter time than it would at operation with the demand regulator. In practice the valve should be opened slowly and only a minimum flow should be used.



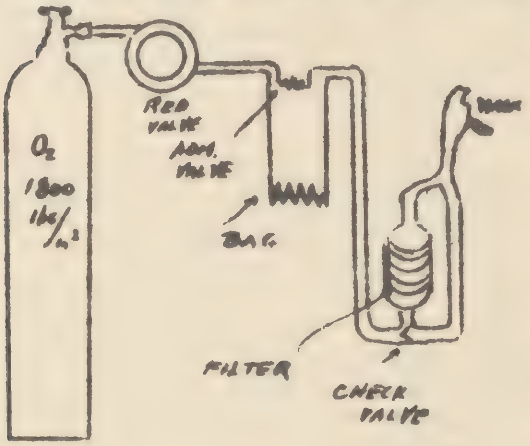
The demand regulator operates in the following manner. When the oxygen supply cylinder valve is opened, oxygen flows into the reducing valve, expanding the bellows and closing the valve. Second, on inhalation at the facepiece, a differential pressure is created across the diaphragm, causing it to open the admission valve and oxygen flows through the valve and breathing tube to the facepiece and user.



Although this demand type apparatus operates satisfactorily, there is a certain amount of inefficiency and waste of oxygen because of the fact that breathing out wastes 95 parts per hundred of oxygen. In order to make this clear, let us recall that expired breath contains roughly 5% carbon dioxide which contaminates the expired breath and makes it impossible for a person to rebreathe air. Now, in the case of breathing pure oxygen through a demand regulator one breathes in 100% oxygen and breathes out 95% oxygen plus 5% carbon dioxide. If an arrangement could be made for the removal of this 5% carbon dioxide then one could recover 95 parts per hundred of oxygen from each expired breath. That, essentially, is the mechanism of the third type of oxygen equipment which we will discuss, namely the <u>Rebreather Apparatus</u>. By the use of a chemical filter it is possible to

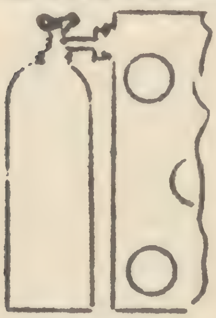


remove from the expired breath the contaminating carbon dioxide and also some of the water vapor. Let us look at a diagram of the rebreather type of equipment. We see first the oxygen supply bottle, then a breathing bag from which we see a hose connection leading to the face piece, and, since this is a closed system, the expired breath comes back down through a breathing tube and is passed through a canister which contains a chemical filter for the removal of carbon dioxide. In this apparatus, the wearer breathes oxygen in a closed circuit and the exhaled oxygen is retained and used after purification by removal of the carbon dioxide. The expired oxygen goes to the breathing bag and when the bag becomes partly depleted a small trip-valve is opened and the oxygen supply is automatically replenished. In this way there is always a supply of oxygen necessary for normal function.



SEE FULL PAGE FLOW DIAGRAM

Two types of oxygen rebreathing apparatus have been developed; an individual oxygen supply type, and a central or manifold oxygen supply type. The operation is essentially the same, the only difference being in the source of oxygen. The individual supply carries a small cylinder whereas the central supply is operated by a large central storage cylinder with outlets along the oxygen line mounted in the fuselage. In the Chamber, as is true in most large aircraft, the central oxygen supply type is used. In the use of the rebreather type of apparatus it is essential to remember that the apparatus is more complicated than either the demand or constant flow and for that reason needs a more careful check. Whenever one uses the rebreather type of apparatus one should proceed to go through the following

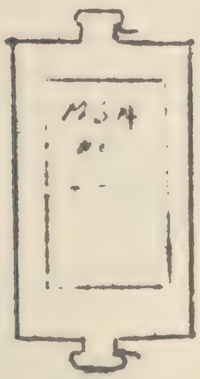


INDIVIDUAL O2

five steps in their check list.

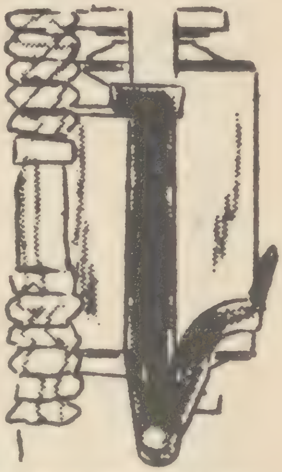
1. Oxygen supply. No apparatus will operate without an oxygen supply. If one uses the individual type apparatus, one checks to see that the hose connections are properly fixed between the oxygen bottle and the rebreather breathing bag and checks on the gauge to see that there is an adequate supply of oxygen for the duration of the flight. In the use of the central supply system it is necessary to connect the oxygen hose line to the fuselage supply line and this is done by inserting the male plug into the female valve outlet. A small thumb button is depressed and the plug inserted and given a quarter-turn to the right until it fits snugly. In the use of the central supply system in aircraft it is of importance to check constantly in order to prevent the plane vibration from shaking the connection from its fitting. In general, a properly connected fitting will not shake loose; However, precautionary checking during flight is important. When the oxygen supply lines have been connected and the oxygen supply checked by the reading of the gauge, the user is ready for the second step in our check list.

2. Canister. Under this item we consider first the canister, second its proper opening, third its proper insertion in the apparatus, and fourth its lifetime. Canisters are filled with a caustic, irritating chemical, which, when it comes in contact with the skin, particularly the eyes, nose, or throat, can do a moderate amount of damage. It is, therefore, important to open the canister with caution for often, especially at altitudes above the ground, the air rushing out of the canister carries with it fine particles of caustic, which, if they were directed toward some crewmate or toward the user's face, would do damage. To open the canister properly, turn the end which you are opening away from you toward the deck and pull the small metal tab out in order to break the seal and then pull the covering open.. A small rubber wafer is inserted in the factory and should be removed. Occasionally faulty canisters do not have this wafer and if such be the case discard the canister and take a new one. After opening one side, open the other and you are ready for the insertion of the canister into the apparatus. A word here about opening the canister. This is a job meant for each man for his own canister; do not rely on your plane captain or your buddy

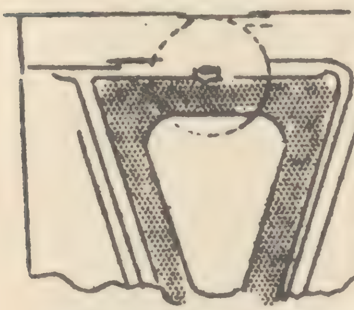


CANISTER

for opening it. Since the life of a canister is limited to two hours from the time of opening, the only way you can be sure that yours is a fresh and new one is for you to open it and insert it. Having opened the canister we now insert it, either side up. See that it is aligned properly and not out of line, and then close the toggle. If the canister has been inserted properly it will take no force to close the toggle. If force is necessary, the canister has not been aligned properly and should be re-aligned. Forcing a toggle can result in the denting of the canister ends with a resultant failure of adequate oxygen supply.



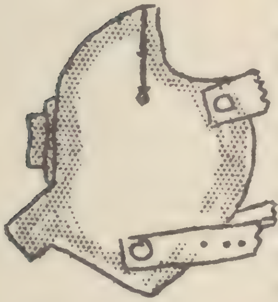
3. Leaks. Having inserted the canister, our next step is to check our rebreather system for possible leaks or faulty connections. This is done in the following way. The small button valve connected to the face piece is closed by pushing it down. This is done to close the system; otherwise the oxygen would flow from the tank through the breathing bag, through the nose connections, out into the room and the system could not be checked. Having closed this small valve the user then depresses or pushes the wishbone against the breathing bag, until it begins to fill with oxygen. The bag should fill to a moderate taut fullness within five seconds. After the bag is filled, the tester removes his finger from the wishbone, keeping the face piece valve closed, and watches the bag for 10 or 15 seconds.



If the bag remains as taut and full as it originally was, there are no leaks. If, on the other hand, the bag deflates, it is necessary to look for the source of the leak. In doing this one rechecks the oxygen line connection to see that it is fit and snug. Second, one checks the canister to see that it is seated properly and that its ends are not dented. If both are in order, one then checks the breathing bag connection of the oxygen line tube. In order to do this it is necessary first to disconnect the other end of the oxygen line. Occasionally there is a washer seated in this connection. No washer should be in this place and if one

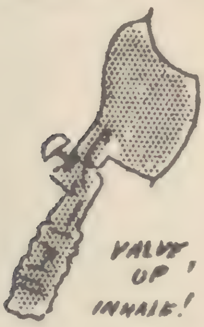
is found it should be removed. A washer in this particular place will reduce the pressure from its necessary 9 lbs. to 1 lb., and is placed there at times in ignorance. If these three checks have been made and the equipment still leaks, exchange the apparatus for a new one.

4. Face piece. Since no two people look the same, no two people's faces are built the same, and yet masks are essentially the same pattern. It is important, therefore, to check the mask to see whether it fits properly. The re-

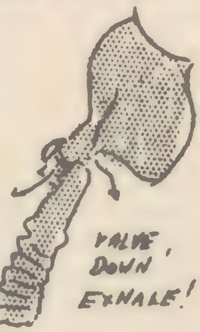


breather type mask is so built that it fits best when the top straps are secured snugly and placed on the top of the head as far as possible. The bottom strap is only a safety strap and should go around the back of the neck loosely. If the user's nose bridge is either very sharp or very broad, it may be necessary to remold the nose piece of the mask. To do this there is a small malleable wire which can be adjusted. To check the mask for fitness one puts it on properly and then, with the nose connection clamped or kinked off by hand, one inhales. If the mask fits properly suction will result and the facepiece will collapse against the face.

5. Washing or flushing out of the apparatus. This is done in order to fill the entire breathing bag and the hose connections with pure oxygen and is done simply by breathing in from the oxygen supply and breathing out to the atmosphere. To expedite this there is a small face piece



valve, the one which was closed in step three to check the system for possible leaks, and this face piece valve is manipulated in the following way. When the user breathes in the valve is up, when he breathes out the valve is down. A simple way to remember the process is to



remember that breathing in the chest goes up; the valve goes up. Breathing out, the chest goes down; the valve goes down. In this way the user breathes pure oxygen in and breathes out to the atmosphere. This breathing in and breathing out with the valve up and down, respectively, is called "flushing out", and three or four flushes should be carried out at the following times. As soon as the apparatus is put on it should be flushed out; every 10 or 15 mi-

nutes in a flight; whenever the user belches or burps, since the intestinal gases are part nitrogen it is important to remove this nitrogen from the system.

This rebreather type of apparatus, which uses a minimum amount of oxygen and which has a high degree of efficiency, must be used intelligently and with constant care to see that the oxygen lines are in order, that the canister is not used too long, and that flushing out is done periodically and regularly.

The fourth type of equipment, which is a recent development, is built upon the demand regulator principle and modified for a more efficient utilization of oxygen. You will recall in the regular demand type oxygen system 100% oxygen is delivered to the user with each inhalation. 100% oxygen is more than is necessary at altitudes above 10 000 ft. and below 34 000 ft., and, therefore, with the old demand type regulator there is always an excess of oxygen delivered to the user. For example, you will recall from the doctor's lecture that when 100% oxygen is being used at 18 000 ft., the oxygen pressure in the lung at that time is 293 mms. of mercury, which is almost three times the amount necessary for normal bodily activity. The recent modification in demand type apparatus, which is

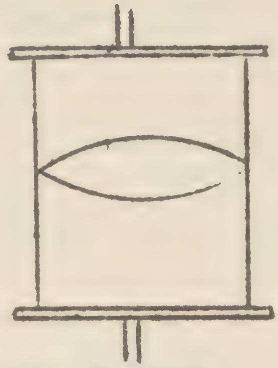
SEE FULL PAGE DIAGRAM

called Dilutor Demand Regulator, corrects this waste of oxygen by mixing proper proportions of atmospheric air and oxygen (delivered from the cylinder), so that an internal lung pressure of oxygen of about 106 mms. is always maintained. In other words, with the dilutor demand arrangement, the lung always has, with each inspiration, a pressure of oxygen comparable to that which exists at sea level, breathing air.

The dilutor demand regulator can be considered as three separate devices combined in one and by simple adjustments any one of the three types can be used. For example, under conditions of operation with the emergency valve opened, the regulator performs as a constant flow

regulator. When the emergency valve is closed and the dilutor demand valve is in its "OFF" position, then the regulator operates as an ordinary demand type regulator delivering 100% oxygen to the user with each inhalation. When the valve is turned to its "ON" position, the device operates to deliver enough oxygen to the user on each inhalation so that a pressure of approximately 107 mms. of mercury is available in the lung.

As far as the operation of this device is concerned, it is simple and quite automatic; the operator has to see, first, that there is an adequate oxygen supply, and, second, that the oxygen supply is turned on. In most planes there is a flow indicator which offers the user an opportunity to see that oxygen is flowing, and then, after fitting of the mask, it is necessary only to see that the regulator valve is in its "ON" position. If this valve is not in its "ON" position, the user will be defeating the purpose of economy introduced by its use. These valves are so designed that the proportions of oxygen and air will be mixed or automatically controlled by the atmospheric pressure, and there is less air in the mixture at 20 000 ft. than at 15 000, and less at 25 000 ft. than at 20 000, which means more oxygen at 25 000 ft. than at 20 000 ft., etc. When an altitude of 33 000 ft. is reached the valve is automatically closed and only pure oxygen reaches the user.

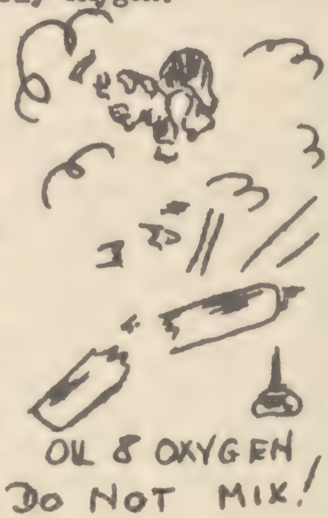


FLOW BLINKER

This type of equipment is being introduced in various Navy aircraft and probably will be used by most Navy personnel. There are two types of products on the market. The demonstration is a Pioneer-Bendix Model. The second type is the Aro-Mix, and, except for one slight difference, their performance and function are the same. This difference is that in using the Aro-Mix it is essential to put the regulator valve to its "OFF" position before opening the emergency valve for constant flow.

SAFETY RULES

This chapter consists almost entirely of safety rules taken from the rules governing various trades in effect at U. S. Naval Air Station, San Diego, California. They are divided into two sections. The following deal with the handling of gas cylinders, particularly oxygen.



1. Do not store full gas cylinders in direct sunlight or in any hot place.

2. Great care must be used to prevent the dropping or bumping of any gas cylinder. Cylinders must be kept in racks or stands or lashed to prevent them from being knocked over.

3. Care must be taken to prevent the contamination by oil or grease with any part of the cylinder, valve or hose.

4. Leather washers must never be used on gas cylinder valves; the regular fiber washer or gasket must be used.

5. The valve protector cap must be kept in place whenever cylinders are not in use.

6. Cylinders must never be used for other than their designated kind of gas.

7. Do not stand in front of gauges when opening the discharge valve.

8. Handling of cylinders by cranes must be done only when proper racks are used. Rope or wire slings are forbidden.

9. Remove regulators and place caps over valves when transporting cylinders by other than regular cylinder trucks.

10. Cylinders must never be dropped or treated roughly.

11. Leaky cylinders must be placed in the open immediately on being noticed.

12. Any charged or partially charged cylinder, of any size, is as potentially dangerous as a loaded shell and must always be handled as such.

13. Should any charged or partially charged cylinder begin to discharge when not held in a vise, every effort should be made to seize it or fall on it to prevent rolling.

14. Cylinders shall never be voided of residual gas unless an approved anti-coil safety cap is tightly screwed on the discharge orifice of the valve. Voiding shall be slowly, in the open air, at least 50 feet from open lights or fires. All other cylinders shall be securely clamped in the cylinder vise.

15. Oxygen and acetylene cylinders shall be stored separately in specially constructed storage locations. Cylinders shall be kept at a minimum and stored and shipped with valve protecting caps in place.

16. Use only the wrench provided for opening valves.

17. Close valves only snug-tight and do not oil or grease them.

18. Never handle the valve on a charged cylinder in such a way that it may unintentionally be opened.

19. Never fill a cylinder beyond its rated capacity.

20. To prevent explosion, use correct type of safety disc properly installed. Allow no stoppage or abnormal restrictions in the discharge lines.

21. Cylinder with a broken safety wire should be weighed to check its contents before use.

22. Oxygen regulators shall be stamped with serial numbers. Those in service shall be tested at intervals of 90 days.

23. Tests shall be conducted and logs maintained listing serial numbers and dates tested.

The safety regulations below deal with the use of air plane dopes and solvents and noxious fuels.

1. Working spaces must be kept clean and in complete order.

2. Extreme care shall be taken in handling and using solvents for cleaning.

3. Inflammable solvents, when used for cleaning by hand shall be used only in approved safety cans.

4. All heated objects shall be kept free of waste and residue.

5. No metals shall be struck together. Heavy nails, hobs or steel plates on soles or heels of shoes are prohibited.

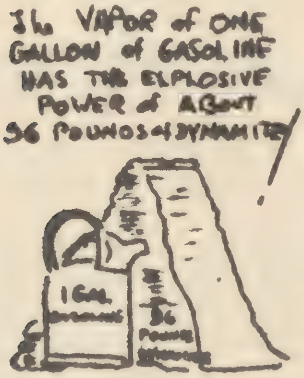
6. Steel scrapers for cleaning concrete floors in the presence of inflammables are prohibited.

7. Only spark-proof tools and approved equipment shall be used in the presence of inflammables.

8. No naked lights, automatic lighters, matches of any kind, or smoking will be tolerated in the presence of dope or solvents.

9. No dope shall be stored in the shop, and none shall be handled in the shop in larger than one-gallon containers. All dope containers and brushes shall be removed at the end of the day and stored in fireproof lockers.

10. Firebills shall be posted and fire frills held at regular intervals.



11. Doors and windows shall be kept closed while doping.

12. All pipe, ducts, or flues shall discharge out of doors at a safe point.

13. Avoid excessive exposure to fumes. If overcome the immediate treatment is removal to fresh air, with artificial respiration, if necessary. Call the doctor.

14. Protective cream shall be applied to skins sensitive to dope and solvents.

15. Do not breathe fumes from welding, cutting, plating, pickling, painting, lead burning, galvanising, or molten metals. If adequate ventilation is not available, use fume type respirator.

16. Attention is directed to the possible injurious toxic effect of fumes generated by metal spraying, particularly with cadmium.

17. All metal spraying must be done in the open air or in well ventilated spaces.

18. Operators must wear masks.

19. Dust type respirators must be worn for chipping red lead, handling fibre glass, insulating materials, for dressing grinding wheels, and for other dusty work where adequate ventilation is lacking.

20. Eye protectors (goggles or shields) must be worn when engaged in acid working, babbitting, breaking metal (scrap work), cleaning castings, overhead drilling, reaming, etc., sawing (circular saw, large diameter, high speed), assisting welder, buffing, and in all work where flying particles are encountered.

21. Rubber aprons, gloves, and rubber boots are to be worn when working in strong acids, alkali, etc.

22. Breathing apparatus must be worn by sandblasters, acetylene welders, paint sprayers, when working in confined areas, and other occupations when necessary.

23. All protectors, such as goggles, respirators, face shields, rubber gloves, and boots, shall be cleaned and sterilized once each quarter when used only by the same operator.

24. Never issue an employee a protector that has been used by another employee until it has been sterilized.

25. Application of luminous paint is restricted to areas and enclosures specially provided for this purpose.

26. Personnel assigned to this work must be familiar with safety precautions as outlined in the Navy Department General Safety Rules, Section #9, Radioactive Luminous Compound.

27. Working areas must be properly constructed, properly ventilated and approved with an approved type of ventilated hooded paint table.

28. Operatorz shall wear prescribed clothing respirators, and gloves, which shall be inspected in a dark room by ultra-violet lamp at the close of working hours.

29. Operators must not point the brush with their lips or fingers.